The prescribing and use of pocket and portable electronic low vision aids for patients with visual impairment

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SUMMARY/ ABSTRACT

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Summary of Thesis

Pocket and portable electronic low vision aids (PELVAs) are relatively new devices designed to enhance vision of people with visual impairment. Therefore, the aim of this thesis was to evaluate their use and prescribing patterns for PELVAs for patients with visual impairment and to inform clinicians of the functions or attributes that are most important when considering their prescription.

Firstly, the parameters (including magnification screen size, luminance contrast, and resolution) of PELVAs were assessed. Magnification and screen size were also compared with the manufacturers' data.

Secondly, data (age, gender, ocular condition, visual acuity, living situation, registration of visual impairment, type of low vision aid prescribed) from 6,668 patients who attended the Low Vision Service for Wales were analyzed to assess the clinicians' prescribing patterns for PELVAs.

Thirdly, reading frequency and duration, and self-reported effectiveness of PELVAs and optical low vision aids for patients with visual impairment were evaluated by using a telephone interview based upon the Manchester Low Vision Questionnaire.

Finally, reading speed was measured for normally sighted subjects with simulated visual impairment who used a PELVA and an optical low vision aid. The factors that could predict reading speed were investigated.

PELVAs enhanced the luminance contrast of high and low contrast letters which may be beneficial for patients with contrast reduction, for example due to cataracts. Variations were found between reported and measured magnification of the PELVA.

Only 10% of adult patients were prescribed a PELVA, and younger males were more likely to use them. A larger proportion of children (36.5%) were prescribed a PELVA. Patients who used PELVAs rated them highly for near vision tasks and were more likely to use PELVAs for reading once a day but for a long duration, whereas optical low vision aids were used more frequently and for a shorter duration. It was found that the reading speed was significantly improved using PELVA and optical low vision for subjects with simulated visual impairment; Bailey-Lovie near visual acuity, high and low contrast Colenbarnder near visual acuity, and number of visible characters were significant predictors of reading speed.

CHAPTER 1: General introduction

Electronic low vision aids have been available for patients with low vision since 1950s (Potts et al. 1959, Genensky et al. 1972). Table mounted electronic low vision aids (commonly known as CCTVs) have existed for many years (Potts et al. 1959, Genensky 1969). Reading speed and duration have been found to be significantly greater with the CCTV systems than with optical devices (Goodrich and Kirby 2001, Peterson et al. 2003). However, their high price and lack of flexibility and portability limited their use (Harper et al., 1999). Head-mounted devices have also been available but the benefits of these over traditional devices have not been demonstrated (Harper et al., 1999).

Pocket and portable electronic low vision aids (PELVAs) have been found to have advantages over other electronic devices and optical low vision aids: 1) they are more portable than other electronic low vision aids (their small size makes them easy to carry and for some to fit in a pocket), 2) they are more affordable than larger electronic devices (less expensive), 3) they are easy to operate (fewer buttons to switch on/ off and to manipulate zoom and luminance), 4) they have flexible focus (some PELVAs can be used at variable distances), 5) they have variable magnification/ zoom levels, 6) larger PELVAs (not mini versions) have a larger field of view than optical devices, 7) they offer contrast manipulation, and 8) they offer different object-background colour combinations.

PELVAs have now become a prescribing option in the National Health Service (NHS) Low Vision Service in Wales (LVSW) (Charlton et al., 2011). With the current pace of technological development, it is likely that in the near future electronic low vision aids will be used by more patients with a visual impairment, especially when conventional low vision aids (e.g. optical magnifiers) are no longer sufficient to meet their requirements (Taylor et al., 2014).

Available literature has evaluated the effectiveness of different low vision aids in assisting patients with a visual impairment to perform daily life tasks (Bullimore and Bailey 1989, Whittaker and Lovie-Kitchin 1993, Bailey et al. 1994, Lighthouse National Survey on Vision Loss 1995, Goodrich and Kirby 2001, Wolffsohn and Peterson 2003, Peterson et al. 2003, Culham et al. 2004, Crossland and Silver 2005, Jutai et al. 2005, Nguyen et al. 2009, Culham et al. 2009, Virgili and Acosta 2009). However, none of these evaluated the effectiveness of PELVAs for people with a visual impairment.

Moreover, agreement between the reported PELVAs parameters' and those found in independent settings has not been evaluated yet. Bullimore and Bailey (1989) reported that manufacturers do not necessarily provide accurate information about the optical parameters of stand magnifiers. Also, Bailey et al. (1994) reported that information provided by manufacturers about low vision magnifiers may not be sufficient to estimate the resolution improvement that they actually provide for visually impaired people. Clinicians have to determine the key parameters of devices used in their practice, as they might be misreported or not reported at all by manufacturers (Bailey

et al., 1994). The authors recommended that ''until manufacturers provide the required technical information about their devices, clinicians must determine these parameters for themselves or obtain the information from other sources" (Bailey et al., 1994).

An important part of studying the effectiveness of a particular management option for patients with a visual impairment, such as PELVAs, was to investigate what a device could actually provide i.e. 'its actual parameters', then to examine if patients requirements can be met by the chosen device. This is important in order to help people and clinicians, to enhance evidence-based decisions to choose the most appropriate device, and to save time, effort and money; by avoiding too much 'trial and error' until they reach a cost-effective decision.

This thesis compliments a randomized control trial being conducted currently by Taylor et al. (2014) to determine the impact and cost effectiveness of prescribing PELVAs. We evaluated PELVAs from different aspects: 1) agreement between the reported PELVAs parameters' (including display screen size and magnification), and those measured in an independent setting, 2) estimation of PELVAs contrast enhancement features and resolution, 3) the prescribing patterns for PELVAs by clinicians already using them, 4) the use and satisfaction of these devices among patients with a visual impairment, and 5) reading performance of patients with a visual impairment using PELVAs.

1.1. Aims/ Objectives

This thesis aims to inform those who prescribe or choose PELVAs about the functions or attributes that are most important when considering their use for patients with a visual impairment.

Thesis objectives include:

- To compare the reported manufacturers' magnification and screen size of PELVAs to that measured in an independent setting.
- To measure the luminance contrast that PELVAs could provide in different independent settings.
- To estimate the resolution limit of currently available PELVAs.
- To describe the clinicians' prescribing patterns for PELVAs for patients with a visual impairment attending a NHS Low Vision Service in Wales.
- To determine the characteristics of patients with a visual impairment who would benefit from PELVAs.
- To assess patients' self-reported satisfaction of PELVAs compared to optical devices.
- To evaluate what patients with a visual impairment use low vision aids (PELVAs and optical) for.
- To evaluate the usefulness of low vision aids for a group of visual tasks such as reading a newspaper, and reading price labels.
- To evaluate the frequency and duration of reading that can be achieved with low vision aids (PELVAs and optical).

- To compare PELVAs and optical low vision aids from the patients' perspective in terms of purpose of use, rating their use and satisfaction, and reading frequency and duration.
- To determine the factors (visual functions and/or devices parameters) that affect reading performance of patients with a visual impairment who are using PELVAs.

This thesis includes eight chapters: The first chapter provides a general introduction to the thesis.

The second chapter titled *'Visual impairment and low vision aids'* includes a literature review on visual impairment in terms of definition(s), prevalence, aetiology, impact, management modalities/ options, and the effectiveness of available management options.

The third chapter titled *'Pocket and portable electronic low vision aids: Do manufacturers provide an accurate description [Magnification and Screen diameter]?'* describes an experiment in which the reported manufacturers magnification and display screen size of PELVAs were evaluated in an independent setting.

The fourth chapter titled *'Luminance contrast and resolution limits of pocket and portable electronic low vision aids measured in independent settings.'* describes an experiment in which the luminance contrast of PELVAs was measured in independent

settings and different room illumination, and the resolution limits using an ISO 12233 resolution chart.

The fifth chapter titled '*The clinicians' prescribing patterns for pocket and portable electronic low vision aids for patients with a visual impairment who attended the Low Vision Service Wales'* includes an analysis of 6,668 records of patients with a visual impairment who attended the Low Vision Service Wales (LVSW) in the year 2011/ 2012. The data set includes demographics of patients such as age, gender, ocular conditions, living situation, registration of visual impairment, and whether a PELVA was prescribed or not. The data set did not include information about whether low vision aids (optical, non-optical, electronic (except PELVA) or substitution aids) were prescribed if any.

The sixth chapter titled '*The use and self-reported satisfaction of pocket and portable electronic low vision aids, and optical low vision aids for patients with a visual impairment'* describes a pilot study that evaluated the use, satisfaction, reading frequency and duration of previously prescribed PELVAs and/ or optical devices for 88 patients with a visual impairment using the Manchester Low Vision Questionnaire (MLVQ) phone interview.

The seventh chapter titled *'Investigation of the factors (visual functions and/ or devices parameters) that affect reading performance of people with simulated visual impairment using low vision aids (pocket and portable electronic low vision aids, and optical low vision aids)'* describes a pilot study, in which normally sighted people with

simulated visual impairment undergo a clinical-based assessment of visual functions and reading performance using both PELVAs and optical low vision aids.

The eighth chapter titled *'Summary of the thesis findings'* includes findings and future work.

CHAPTER 2: Visual impairment and low vision aids

2.1. Introduction

Visual impairment is considered one of the major public health issues. It is becoming increasingly important because of the high prevalence, the projected increase in the number of people who are expected to become visually impaired as populations are ageing, and the significant impact that it has on social, economic, daily life skills performance levels, physical well-being, mental health and psychosocial status (Resinkoff et al. 2004, Lamoureux et al. 2007, Binns et al. 2012, Court et al. 2014).

Moreover, visual impairment impacts on a country's economy as the productivity of people reduces, and more importantly, because of the large amount of direct and indirect expenditure that is required to cover the different types of services for people with a visual impairment (Taylor et al. 2006, Frick et al. 2007, Access Economic 2010, Binns et al. 2012).

Visual impairment affects people of all age groups, it is becoming more prevalent, and the risk of being visually impaired increases as people become older (Eye Disease Prevalence Research Group 2004, WHO 2014). As people age, some causes of visual impairment become more prevalent, such as age-related macular degeneration (AMD) and cataract (Eye Disease Prevalence Research Group 2004, WHO 2014).

This literature review includes a background about visual impairment and low vision aids. Firstly, it introduces the reader to visual impairment in terms of its definitions, classifications, prevalence, aetiology and impact. Then, it describes different management modalities of visual impairment, such as optical and electronic visual aids. Next, it describes electronic low vision aids as new emerging technology including the definition, history of development, classification, advantages and disadvantages of electronic low vision aids. It also includes a review of literature on the prescription pattern of low vision aids and the effectiveness of different management options for patients with a visual impairment; particularly the effectiveness of using low vision aids in improving reading performance for patients with a visual impairment. In addition, it explores methods of assessing reading performance.

2.2. Definition of visual impairment

'Visual impairment', throughout the text, will be used to refer to 'blindness' and 'low vision' (Resinkoff et al., 2004), this description includes the full spectrum of sight loss.

Different definitions have been adopted for visual impairment. Some of these definitions use descriptions of the residual visual function (e.g. visual acuity and visual field) (WHO ICD-10, 2010) whereas other definitions describe the functional limitations caused by visual impairment such as reading, outdoor activities or shopping (Brabyn et al. 2001, Crews and Campbell 2001, Crews and Campbell 2004, Haymes et al. 2002, Lamoureux et al. 2004, Jutai et al. 2005).

Low vision is defined as a permanent visual impairment which cannot be corrected with a conventional optical correction (spectacles or contact lenses) or a surgical intervention (Lueck 2004, Vision Australia 2006b).

According to the World Health Organization (WHO, 1992): "*A person with low vision is one who has impairment of visual functioning even after treatment, and/ or standard refractive correction, and has a visual acuity of less than 6/18 to light perception or a visual field of less than 10 degrees from the point of fixation, but who uses, or is potentially able to use, vision for the planning and/ or execution of a task"* (WHO, 1992).

The WHO has defined visual impairment (i.e. low vision and blindness) in the International Statistical Classification of Diseases (WHO ICD-10, 2003). Categories of visual impairment, based on the best corrected visual acuity, according to ICD-10 are shown in Table 2.1 (WHO ICD-10 2003, WHO 2004, Dandona and Dandona 2006, and WHO ICD-10 2010).

Categories of Visual Impairment (Depending on **Best Possible** Corrected Visual Acuity)	Categories of Visual Impairment (Depending on **Presenting** Distance Visual Acuity)	Visual Acuity (Log MAR equivalent)	
		Worse than	Equal to or better than
---	**0** Mild or no visual impairment		0.48
1 Low vision	**1** Mild visual impairment	0.48	1.00
2 Low vision	**2** Severe visual impairment	1.00	1.30
3 Blindness	**3** Blindness	1.30	1.80
4 Blindness	**4** Blindness	1.80	Light perception
5 Blindness	**5** Blindness	No light perception	
9 Unqualified vision loss	**9** Unqualified vision loss	Undetermined or unspecified	

Table 2.1: Categories of visual impairment based on best corrected visual acuity (Column1) and categories of visual impairment based on presenting visual acuity (Column2) (Adapted from WHO ICD-10 2003, WHO 2004, Dandona and Dandona 2006, WHO ICD-10 2010). Visual acuity was converted into Log MAR visual acuity.

It can be clearly seen from Table 2.1 that categories of visual impairment in the first column are defined based on the best possible distance correction. This might lead to an underestimation of the number of people with visual impairment due to uncorrected refractive errors. Accordingly, the Resolution of the International Council of Ophthalmology and the WHO Consultation on "Development of Standards for Characterization of Vision Loss and Visual Functioning" have recommended that visual impairment should be based on the presenting visual acuity (WHO, 2004) (Table 2.1).

The United States has different definitions for visual impairment. For example, a person would be described as blind if he/ she has visual acuity of equal to or less than 6/60 and as a low vision patient when his/ her visual acuity is less than 6/12 (NEI, 2008). Studies by Klaver et al. (1998), Congdon et al. (2004), and Gunnlaugsdottir et al. (2008) used definitions' from the United States and the WHO ICD-10.

Jutai et al. (2005) [the Vision Rehabilitation Evidence Based Review VREBR] have defined low vision as: *"Any condition of diminished vision uncorrectable by standard glasses, contact lenses, medication or surgery that disrupts a person's ability to perform common age-appropriate visual tasks. Irresolvable low vision results from uncorrectable and untreatable conditions, whereas unresolved low vision results from correctable but uncorrected, and treatable but untreated, conditions"* (Jutai et al., 2005).

The Low Vision Services Consensus Group of the Royal National Institute of Blind People (RNIB), in the UK, defined a low vision patient as**:** *"...one who has an impairment of visual function for whom full remediation is not possible by conventional spectacles, contact lenses, or medical intervention and which causes restrictions in that persons everyday life... This definition includes but is not limited to those who are registered as blind and partially sighted"* (Low Vision Services Consensus Group 1999, Sinclair and Ryan 2012).

This means that considering patients to be eligible for low vision services or rehabilitation should not rely only on the basis of clinical measures such as visual field or visual acuity, but there should be consideration given to the impact that visual impairment has on people with visual impairment (Binns et al., 2012). Rahi et al. (2009) employed the term 'socially significant visual impairment' to refer to people who are not eligible to legally drive (visual acuity of less than 6/12).

2.3. Prevalence of visual impairment

2.3.1. Global prevalence of visual impairment

Globally, the number of people with a visual impairment of all age groups, was estimated to be 285 million; 39 million blind and 246 million with low vision (Pascolini and Mariotti 2012, RNIB 2013, WHO 2014). Visual impairment is unequally distributed throughout the world; with the least developed countries being more affected (WHO, 2014). About 90% of people with a visual impairment live in developing countries (WHO, 2014).

Visual impairment is also unequally distributed among age groups; 65% of people with visual impairment and 82% of people with blindness are aged 50 years and older (WHO, 2014).

Worldwide, the population is increasing with a shift toward a higher percentage of older people (UN, 2013). The increase in life expectancy because of improved sanitation, health care and food supply, and the noticeable decrease in birth rate as women have become more educated, and there has been a decline in the mortality rate of children: all these factors could lead to a situation where there are more elderly compared to children (UN, 2013). It has been estimated that by 2050 the life expectancy at age 60 is projected to increase from 20 to 22 years in the more developed countries and from 17 to 19 in the least developed countries (UN, 2013). Globally, the proportion of people aged 60 years and older is expected to increase from 12%, in 2013, to 21%, in 2050 (UN, 2013). It has been projected that the proportion of people aged 60 years and older will

continue to increase by three folds, while the proportions of younger ages become constant (UN, 2013).

Prevalence of visual impairment varies with gender; with females having a more significant risk of developing visual impairment, with ratios range from 1.5 to 2.2 (Resinkoff et al., 2004). About 57% of people with a visual impairment (n=230 million) in 2010 and 60% of blind people (n=36.5 million) were females (Stevens et al., 2013).

2.3.2. Prevalence of visual impairment in developed countries

In developed countries, the prevalence of low vision as well as its social and economic impact cannot be accurately estimated (Bailey et al., 2006). In Europe, it is estimated that there were 30 million people living with sight loss (RNIB, 2013).

The prevalence of self-reported visual impairment in the adult American population was about 9% (Ryskulova et al., 2008). According to Bailey et al. (2006), the prevalence of legal blindness was about 0.2% of the total population, in the United States. The vast majority (about 80%) of people that were eligible to be defined as legally blind had some residual vision that can be used in a way to improve the performance of their daily life tasks, over 50% of the legally blind people were over the age of sixty (Bailey et al., 2006).

In Canada, there were 836,000 people with a visual impairment: 1) 243,000 over the age of 75, 2) 367,000 over the age of 65, 3) 688,000 over the age of 45, 4) 128,000 between 15 and 45 years old, and 5) 19,700 younger than 15 years old (The Elderly Working Group

of the World Blind Union, 2011). People with a visual impairment were defined as having difficulty seeing ordinary newsprint or an inability to recognize faces at four meters with habitual spectacles. It was also found that more than one in eleven Canadians over the age of 65, and more than one in eight over the age of 75 experience severe vision loss that cannot be corrected with standard eyeglasses (The Elderly Working Group of the World Blind Union, 2011).

2.3.3. Prevalence of visual impairment in the UK

Two million people in the UK are estimated to have a visual impairment and 360,000 are registered as sight impaired or blind (Access Economic 2009, NHS 2013, RNIB 2014). A total of 80,000 of UK adults (working age 18-64 years) have a visual impairment (RNIB, 2014). There were 25,000 children aged 16 years and under blind or partially sighted (RNIB, 2014).

A larger proportion of older people have a visual impairment (Access Economic 2009, RNIB 2012). In the UK, according to RNIB UK statistics (2012), one in five people aged 75 years and older have sight loss, but one in two people aged 90 years and older are affected (RNIB, 2012). However, this figure includes those with correctable/ treatable visual impairment such as refractive error or cataract.

Evans et al. (2002) reported that out of 14,600 people aged 75 years and older from 53 GP practices in the UK, there were 12.4% (1,803) with a visual impairment. Of them, 10.3% (1,501) were recognized as having low vision (binocular visual acuity < 6/18),

whereas 2.1% (302) were recognized as blind (binocular visual acuity < 3/60). In their study, 6.2% of people aged 75 to 79 years, and 36.9% of people aged 90 years and older had a visual impairment. Also, for people aged from 75 to 90 years, there were around 0.6% with blindness, this ratio was increased to 6.9% for people aged 90 or older (Evans et al., 2002). They also found that about 20% of people aged 75 years and older had a binocular visual acuity of less than 6/12 (Evans et al., 2002).

Out of 2 million people with a visual impairment in the UK; only 360,000 people were registered (Access Economic, 2009). Out of 34,410 certificates received in the year 1999/ 2000, 32,895 were registered (13,788 were registered as blind and 19,107 as partially sighted) (Bunce and Wormald, 2006). As people become older they are more likely to be registered. Bunce and Wormald (2006) reported that 83% of people who were registered as blind and 82% of people who were registered as partially sighted were aged 65 years and older. In England, there were 143,385 people who were registered as blind and 147,715 people were registered as partially sighted; 61.3% of them aged 75 years and older (Health and Social Care Information Centre, 2014). The proportion of people with a visual impairment, who were registered by age in England, in 2014, is shown in Figure 2.1.

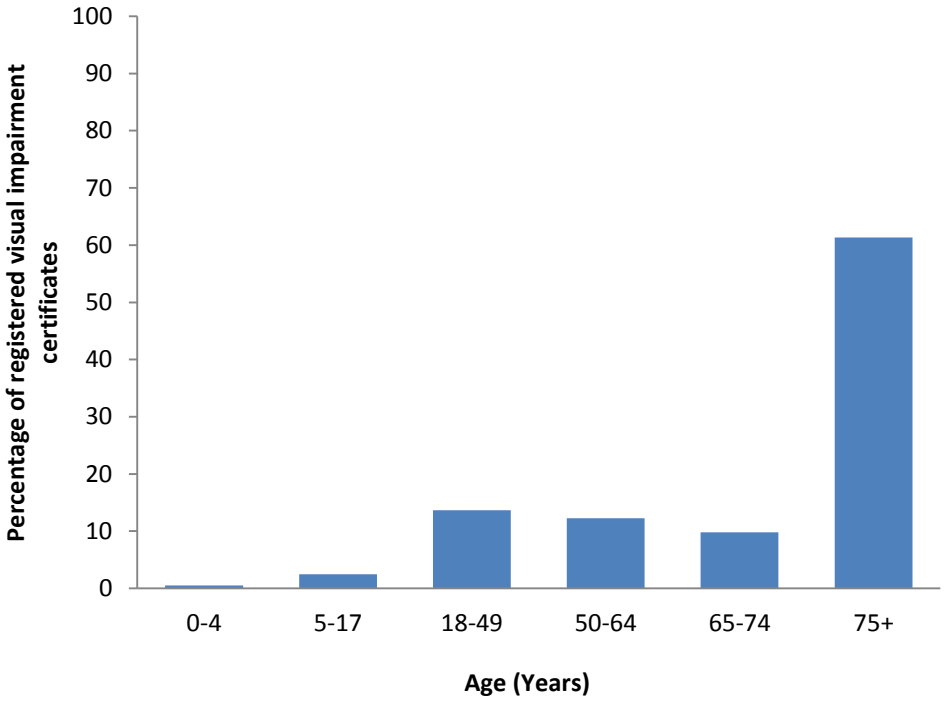


Figure 2.1: The proportion of people on the register of visual impairment in England, in 2014, by age (years) [n=143,385]. Data obtained from Health and Social Care Information Centre (2014).

2.3.4. Variation in the reported prevalence of visual impairment

Different studies have reported different statistics regarding the prevalence of visual impairment (Binns et al., 2012). That may be attributed to the following factors: 1) different definitions of visual impairment that were employed in collecting data, 2) different methods of collection data and different sample sizes, 3) regions of study whether in developed or developing country, and 4) the age of the study population (Binns et al., 2012).

As previously mentioned in Section 2.2, the definition of visual impairment differs which will affect the estimates (Binns et al., 2012). For example, the Lighthouse National

Survey on Vision Loss (1995) and the National Health Interview Survey in the United States (Ryskulova et al., 2008), described visual impairment according to the self-reported visual difficulties experienced by individuals. Others have described visual impairment on the basis of visual acuity and clinical measures (Klaver et al. 1998, Congdon et al. 2004, Gunnlaugsdottir et al. 2008, Rahi et al. 2009). For example, an MRC-funded trial of assessment and management of older people in the community defined visual impairment based on the presenting visual acuity of < 6/18 (Evans et al., 2002). Van-Der Pols et al. (2000) defined visual impairment based on pin hole visual acuity of < 6/18, and the Blue Mountain Eye Study defined visual impairment based on the optimal subjective refraction after objective refraction (Attebo et al., 1996).

Also, the size of study population and the study method affect the prevalence estimates (Binns et al., 2012). Large population studies try to collect data from the community (Buch et al. 2004, Gunnlaugsdottir et al. 2008, Klaver et al. 1998), whereas other studies investigated the registration of visual impairment (Bunce and Wormald, 2006). The number of people that are registered as visually impaired will depend on a number of factors/ criteria (e.g. definition of visual impairment in a particular country, age, gender, the willingness of people to be registered, the cause of visual impairment, and the presence of concurrent disabilities) (Binns et al., 2012).

In the UK, registration of patients with a visual impairment as 'severely sight impaired' (i.e. blind) or 'sight impaired' (i.e. partially sighted) is voluntary and is initiated through certification of visual impairment by an ophthalmologist (Bunce and Wormald, 2006). In

addition, people who gain a certificate of visual impairment from ophthalmologists choose if they want to be included in their local authorities' register of visual impairment (Health and Social Care Information Centre, 2014). Therefore, this approach will lead to underestimation of the number of visually impaired as not all people who are eligible are registered (Barry and Murray 2005, Binns et al. 2012).

2.4. Aetiology of visual impairment and prevalence of visual impairment by cause

The most common eye conditions that cause visual impairment worldwide are age-related macular degeneration (AMD), cataract, diabetic retinopathy, glaucoma and uncorrected refractive error (AMD Alliance International, 2010).

However, the distribution of causes of visual impairment is not similar for all populations. The main causes of visual impairment in a particular population might depend on different factors or inclusion criteria such as 1) age group (elderly, adults, and children); for example elderly have a greater prevalence of age-related ocular diseases such as AMD and cataract whereas children have a greater prevalence of cortical visual impairment, 2) liability of treatment of eye conditions (i.e. treatable causes e.g. cataract and refractive errors, irreversible e.g. glaucoma, or treatable but not treated e.g. uncorrected refractive errors), 3) whether the study population from a developed or a developing country, and 4) participants generic health (Bunce and Wormald 2006, Binns et al. 2012).

Globally, Pascolini and Mariotti (2012) and WHO (2010) estimated that the major causes of visual impairment in 2010 were uncorrected refractive errors (43%) and cataract (33%), and the major cause of blindness was cataract (51%). Other causes of visual impairment included glaucoma (2%), AMD (1%), diabetic retinopathy (1%), trachoma (1%), and corneal opacities (1%).

Developed countries have higher prevalence of irreversible or untreatable causes such as AMD, compared to developing countries where there is a higher prevalence of visual impairment due to treatable or preventable causes such as refractive error and cataract (Pascolini et al., 2004).

In Canada, the major causes of visual impairment have included age-related macular degeneration, diabetic retinopathy, glaucoma, cataracts, and refractive errors (The Elderly Working Group of the World Blind Union, 2011). The prevalence of vision loss in Canada, by cause is shown in Table 2.2.

Cause	All ethnicities		White		AVM*	
	Number	% total	Number	% total	Number	% total
AMD**	89241	10.9	84641	10.8	4380	12
Cataract	133836	16.4	120685	15.5	13151	36.1
Diabetic Retinopathy	29920	3.7	20992	2.7	8928	24.5
Glaucoma	24937	3.1	22565	2.9	2373	6.5
Refractive error/ other	539236	66	531650	68.1	7586	20.8
All vision loss	817171	100	780534	100	36417	100

* Aboriginal and Visible Minorities (AVM)
**Age-related Macular Degeneration

Table 2.2: The prevalence of vision loss in Canada, by cause (The Elderly Working Group of the World Blind Union, 2011).

In the UK, there are approximately 2 million people with sight loss; the five major causes include refractive error, AMD, cataract, glaucoma, and diabetic retinopathy (Access Economic 2009, RNIB 2013). It is estimated that half of sight loss in the UK could be prevented (Access Economic 2009, RNIB 2013). Table 2.3 shows the estimated percentage of the main causes of sight loss in the UK adults.

Sight loss (partial sight loss and blindness)		Blindness only	
Main Causes	**Percentage (Number)**	**Main Causes**	**Percentage (Number)**
AMD	16.7% (300,000)	AMD	50.5% (110,000)
Cataract	13.7% (246,000)	Cataract	12.5% (27,000)
Glaucoma	5.3% (95,000)	Glaucoma	16.6% (36,000)
Diabetic retinopathy	3.5% (62,000)	Diabetic retinopathy	8.7% (19,000)
Refractive error	53.5% (960,000)	Refractive error	2.1% (5,000)
Other causes	7.4% (133,000)	Other causes	9.7% (21,000)

Table 2.3: The main causes of sight loss (partial sight loss and blindness) in the UK (Access Economic, 2009).

Causes for certification/ registration of visual impairment in the UK:

The main causes for certification of visual impairment in England and Wales in 1999/2000 were AMD followed by glaucoma and diabetic retinopathy; blindness was due to AMD (57.2%), glaucoma (10.9%), diabetic retinopathy (5.9%) and partial sight was due to AMD (56%), glaucoma (10.2%), diabetic retinopathy (7.4%) (Bunce and Wormald, 2006). Bunce et al. (2015) reported that out of 23,616 visual impairment certificates in England in 2011/2012, 11,546 (57%) people had AMD (geographical, neovascular, or mixed). The much higher percentage of people with AMD in both studies of causes of certification of sight impairment compared to that reported by Access Economic (16.7%) (Table 2.3) (Access Economic, 2009) was because if the main reason for sight loss is correctable e.g. caused by refractive error or cataracts, a person is usually not offered certification of sight impairment.

Liew et al. (2014) compared causes of blindness certification in working age adults in England and Wales. The authors reported that the main causes for certification of blindness in 1999/ 2000 were diabetic retinopathy/ maculopathy (17.7%), hereditary retinal disorders (15.8%) and optic atrophy (10.1%) (Liew et al., 2014). The main causes for certification of blindness in England and Wales working age adults in 2009/ 2010 were hereditary retinal disorders (20.2%), diabetic retinopathy/ maculopathy (14.4%), and optic atrophy (14.1%) (Liew et al., 2014). The increased certification for inherited retinal disorders might be due to an improvement in the certification of existing sight impairment because of increased community awareness or due to an increase in the

prevalence of these disorders (Liew et al., 2014). On the other hand, the decreased certification for diabetic retinopathy/ maculopathy might be related to the introduction of nationwide diabetic retinopathy screening programmes in England and Wales and improved glycaemic control (Liew et al., 2014).

Children with visual impairment usually develop it before their 2nd month of life (Blohme and Tornqvist, 1997). In the UK, aetiology of visual impairment in children is variable and 'visual impairment' is often considered a small part of other conditions and disabilities that children may have (Bodeau-Livinec et al., 2007). More than 75% of visually impaired children have additional disorders or diseases, and about one-tenth of them die within one year of diagnosis (Rahi and Cable 2003, Bodeau-Livinec et al. 2007). It has been suggested that prenatal factors could be the cause of 60% of visual impairment cases in children, and three quarters of visual impairments in children cannot be prevented or treated with the current knowledge (Flanagan et al. 2003, Rahi et al. 2009). In the UK, the main causes of severe visual impairment in children include: cerebral defects such as cortical visual impairment, disorders of the optic nerve, and retinal disorders (Rahi and Cable 2003, Access Economic 2009).

2.5. Impact of visual impairment

Visual impairment is one of the major global health problems; the preventable causes contributed to as much as 80% of the total global burden (WHO, 2011).

Visual impairment has a significant impact on people's lives at all age groups. People with a visual impairment find it more difficult, or even impossible, to perform daily life activities independently (Crews and Campbell 2001, Brabyn et al. 2001, West et al. 2002, Haymes et al. 2002, Lamoureux et al. 2004, Chia et al. 2004, Cacciatore et al. 2004, Langelaan et al. 2007), and they have restricted mobility and orientation (Turano et al. 2004, Ballemans et al. 2011). This may result in a higher incidence of falls, hip fractures, depression, and social isolation and lower productivity which in turn may affect a country's economy (Rajala et al. 2000, Lord and Dayhew 2001, McCarty et al. 2001, Wang et al. 2001, Ivers et al. 2003, Colenbrander 2003, De-Boer et al. 2004, Chia et al. 2004, Freeman et al. 2005, Taylor et al. 2006, Frick et al. 2007, Nazroo and Zimdars 2010, Pawar et al. 2010, Brown and Barrett 2011, Chou et al. 2013).

Social and functional, as well as psychological, disabilities due to visual impairments have a significant negative impact on people's quality of life (Brown et al. 2002, Chia et al. 2004, Thiagarajan et al. 2005, Langelaan et al. 2007), and increase the risk of mortality (Rajala et al. 2000, Wang et al. 2001, McCarty et al. 2001, Lee et al. 2002, Freeman et al. 2005).

In developed countries, daily life activities such as reading, driving vehicles, and watching television are mainly restricted by the level of vision that people have (West et al. 2002, Lamoureux et al. 2004, Vu et al. 2005, Varma et al. 2006, Ramulu et al. 2012, Bailey 2012, Rubin 2013).

In this section, the impact of visual impairment has been divided into: daily living tasks, psychosocial impact, impact on health, and impact on economy.

2.5.1. Daily living tasks

Activities of Daily Living (ADLs) include tasks that people do on a normal daily basis such as self-care, social activities, mobility, driving, reading and sporting (Kane and Kane, 1981). This might be divided into 'basic ADLs' (i.e. necessary self-care tasks) such as eating and personal hygiene, and 'instrumental ADLs' that include tasks that are not necessary for basic existence but they allow people to live independently in the community such as checking telephone numbers. These make independent living and integration with the community more achievable (Kane and Kane, 1981).

To which level a patient with visual impairment is independent can be evaluated by referring to his/ her ability to perform daily living tasks (Binns et al., 2012). Adults with a visual impairment have less functional abilities in terms of both basic and instrumental ADLs than those without (Crews and Campbell 2001, Brabyn et al. 2001, West et al. 2002, Lamoureux et al. 2004, Hassell et al. 2006, Alma et al. 2011, Alma et al. 2012).

Reading, outdoor mobility, shopping and leisure activities were found to be the greatest limitations in people with a visual impairment (Lamoureux et al. 2004, Chia et al. 2004, Rubin 2013). The risk of falls and hip fractures increases significantly due to restricted mobility and orientation skills among people with a visual impairment (Lord and Dayhew 2001, Ivers et al. 2003, Chia et al. 2004, Patino et al. 2010, Ballemans et al. 2011).

The ability to perform basic and instrumental ADLs among patients with a visual impairment can be reduced due to reduced contrast sensitivity, visual acuity and visual fields (Haymes et al., 2002). Tabrett and Latham (2011) reported that visual functions, particularly distance and near visual acuities without the use of low vision aids, were the best predictors among visual function of 'self-reported vision related activity limitations'. Harper et al. (1999) found that a reduction in visual acuity, loss of contrast, and visual field scotomas could impact on patients' ability to read, to write, to recognize faces and to watch television .

However, the evaluation of both ability and dependence of performing daily living tasks might also be required to understand the functional abilities such as orientation and mobility in people with a visual impairment (Binns et al., 2012). For example, mobility (i.e. the physical ability to move in a typical, safe and organized way through the surrounding environment) and orientation (i.e. as the ability of an individual to recognize and to locate a position of an object relative to the environment) are restricted in people with a visual impairment and they can affect independent travelling and movement (Ballemans et al., 2011).

On the other hand, the Vision Rehabilitation Evidence Based Review VREBR (Jutai et al., 2005) suggested that there might be different considerations (e.g. how patients perceived their visual impairment or how it affected their living) that would affect the functional performance of patients with a visual impairment. Jutai et al. (2005) have

summarised the possible interpretations of the impact of visual impairment on functional performance in Table 2.4.

There is impact on functional performance	No impact on functional performance
Visual impairment results in a loss of function of **limited** consequence to the individual.	Visual impairment affects one eye only
Visual impairment results in a loss of function of **significant** consequence to the individual.	Visual impairment affects measurable dimensions of vision, but these **do not result in any perceived impact** on functional performance of the individual

Table 2.4: The possible impact of visual impairment on functional performance [The Vision Rehabilitation Evidence Based Review VREBR (Jutai et al., 2005)].

2.5.2. Psychosocial impact

Visual impairment has a significant impact on the psychosocial aspect of people's lives (Rovner and Ganguli 1998, Evans et al. 2007, Binns et al. 2012). For example, Evans et al. (2007) found that there was a correlation between visual impairment and depression in 13,900 visually impaired over 75 years old. They reported that about 13.5% of the sample was found to have depression, compared to only 4.9% of the control group (people with normal vision). After adjusting for age and gender, Evans and colleagues also found that there was a high correlation between visual impairment and limitation of performing daily activities that may result in depression (Evans et al., 2007). Brody et al. (2001) reported that the prevalence of depression was 32.5% in 151 older American adults as a result of age related macular degeneration, which is almost twice the prevalence in the normally sighted American older adults.

Also, in a study of 584 American people with a visual impairment who attended rehabilitation services, 7% had 'major depression' and about 27% had 'sub-threshold symptoms' (Horowitz et al., 2005). Van-Der et al. (2015) found that visual impairment increased the incidence of major depression, sub-threshold depression, and anxiety disorders.

As it can be clearly seen, there is a variation in the prevalence of depression (psychosocial impact) among the visually impaired; this variation has been explained by Evans et al. (2007) to be a result of differences in 'confounding factors controlled' of the sample involved in each study.

Psychological status also has been found to have an impact on people's functional disabilities (Shmuely-Dulitzki et al. 1995, Rovner and Ganguli 1998, Brody et al. 2001, Lamoureux et al. 2004). For example, Brody et al. (2001) found that there were higher disability scores for self-reported functional ability for all measures among people diagnosed with depression. Moreover, Tabrett and Latham (2011) found that depression and adjustment to vision loss had a significant impact on 'self-reported vision related activity limitations' without regards to the severity of visual impairment. On the other hand, Lamoureux et al. (2004) found that mental and physical health as well as distance vision were independent predictors for limitation in ADLs.

2.5.3. Impact on general health

Visual impairment was found to affect the level of people's general health, and increase the risk of falls, injuries, hip fractures, and death rate, described earlier in this chapter. According to a report from the Landmark Framingham Eye Study, visual impairment was responsible for about 18% of hip fractures of older Americans (Kahn et al., 1977). Studies also found that that visual impairment can cause an increase in mortality (death) rate (Rajala et al. 2000, McCarty et al. 2001, Wang et al. 2001, Lee et al. 2002, Freeman et al. 2005). Also, Cimarolli et al. (2012) found that vision impairment could preclude patients with a visual impairment from using occupational therapy.

Jacobs et al. (2005) found that older patients with a visual impairment had significantly poorer self-rated health and increased visits to the emergency room, hospitals admission, tiredness, and mortality. Also, visual impairment was associated with reduced well-being with impact on health and life similar to the impact of major diseases such as stroke (Chia et al., 2004). Older people who have cataract had poorer perceived health and well-being compared to controls (Polack et al., 2010).

It has been estimated that other disabilities or disorders and health problems occur in about two third of patients with a visual impairment (Mahoney et al., 2008). In children with a visual impairment the risk of traumatic injuries to the teeth and mouth was higher compared to normally sighted children (Mahoney et al., 2008).

Cupples et al. (2012) suggested that visual impairment adversely affected the health and well-being of patients, and patients with a visual impairment were more likely to have limited access to health care facilities and information.

It was found that patients with a visual impairment were more likely to have more multiple disorders or disabilities compared to normally sighted people (Court et al., 2014). Also, the prevalence of physical health conditions and the prevalence of mental health conditions were higher in patients with a visual impairment (Court et al., 2014).

2.5.4. Economic impact

The impact of visual impairment on the economy is attributed by direct costs (related to illness) including medical, non-medical expenses, and health related costs (Drummond, 2005) and indirect costs (e.g. productivity loss due to illness) (Ament and Evers, 1993).

Globally, the estimated total cost (i.e. direct and indirect costs) of visual impairment has been estimated to be 2,954 billion US dollars ($), in 2010. This was $2,302 billion as a direct cost, and $652 billion as indirect costs. About 12% ($343 billion) was attributed as visual impairment due to AMD (AMD Alliance International, 2010).

“Disability adjusted life years” (DALY) is a concept that has been adopted by WHO in 2000 to explain the overall disease burden; it is expressed as years of life lost due to ill health, disability or early death (Suttie et al., 2011). Globally in 2010, mild and moderate visual impairment contributed to about 51million DALYs, while blindness contributed to

68 million DALYs. Six million DALYs were attributed to AMD alone (AMD Alliance International, 2010).

Koberlein et al. (2015) reviewed studies of the cost of visual impairment prior to 2012, and reported that the global mean annual direct medical costs per patient, in US dollar purchasing power parities ($ PPP), was $ PPP12,175-14,029 for moderate visual impairment, $ PPP13,154-16,321 for severe visual impairment, and $ PPP14,882- 24,180 for blindness. Purchasing Power Parities (PPP) is a technique used to determine the relative value of different currencies. It converts local currencies into international dollars by taking the purchasing power of different national currencies into account and eliminating differences in price levels between countries (Koberlein et al., 2015). Direct costs are the actual expenses related to visual impairment and include medical costs, non-medical costs and other direct costs (medical costs are the cost of resources used for treating visual impairment; non-medical costs include costs caused by visual impairment but not attributed to medical treatment e.g. residential care or transportation; other direct costs include informal care, time spent in treatment by patients or caregivers) (Koberlein et al., 2015).

Globally, the mean annual direct non-medical costs including the provision of assistive aids, home modifications and home based nursing, per patient, were higher for a patient who's visual acuity was ≤ 20/80 ($ PPP 608.71) compared to a patient with a visual acuity of ≥ 20/20 ($ PPP 53.90) (Schmier et al. 2009, Koberlein et al. 2015).

The annual estimates of the indirect costs (such as productivity loss and absence from work) of visual impairment and blindness in Canada and the USA was $ PPP 4,974 to 5,724 million (Rein et al. 2006, Cruess et al. 2011, Koberlein et al. 2015).

Frick et al. (2007) assessed the excess costs associated with visual impairment. They found that there were $2.8 billion excess costs. Home care was the main contributor to this figure, and when they considered the additional costs of the loss of quality of adjusted life years the estimated total annual impact of visual impairment was $16 billion. Moreover, the annual cost of treatment of hip fractures due to visual impairment in older Americans was $2.2 billion (Kahn et al., 1977).

In terms of cost and economic impact, visual impairment was ranked seventh (after cardiovascular diseases, musculoskeletal disorders, injuries, mental disorders, cancer, and dementia) and ahead of coronary heart disease, diabetes, depression and stroke (Taylor et al., 2006). The estimated total cost of visual impairment in Australia was 9.85 billion Australian dollars (the loss of wellbeing 4.8 billion Australian dollars) (Taylor et al., 2006).

In the UK, the total direct NHS expenditure on eye health was £2.64 billion (£496 million as primary care costs, £536 million as inpatient costs, £677 as outpatients' costs, and £370 million as the cost of care including residential and community care) and the indirect cost was £5.3 billion (RNIB, 2013).

In the UK in 2008, the total health expenditure on visual impairment, in adults, was estimated to be £22 billion (£2.15 billion as direct costs, £4.34 billion as indirect costs, and £15.5 billion as burden of disease costs i.e. years lost due to morbidity and years of life lost due to premature death) (Access Economic, 2009). Also, the total annual expenditure on visual impairment due to AMD was estimated to be £1.6 billion (Minassian and Reidy, 2009). Table 2.5 shows the estimated annual costs of the major causes of visual impairment, in the UK between 2010 and 2020.

Cause of visual impairment	Total cost (£)
AMD	1.6 billion
Cataract	995 million
Diabetic retinopathy	680 million
Glaucoma	542 million

Table 2.5: The estimated annual cost of visual impairment by cause, in the UK between 2010 and 2020 (Minassian and Reidy, 2009).

Meads and Hyde, in 2003, analysed the 'main cost factors' that were associated with blindness due to AMD in the United Kingdom. They found that the cost of blindness for the first year ranged between £1,375 and £17,100 with an average of about £6,455 per person, this number was reduced to £6,295 per subsequent year. They found that the cost of residential care was the highest, and that 30% of people with visual acuity of 6/60 would require residential care services within one year from diagnosis (Meads and Hyde, 2003). The authors reported that the costs associated with visual impairment vary depending on patient's age and his/ her diagnosis (Meads and Hyde, 2003).

2.6. Management modalities of visual impairment

Different visual functions can be affected in a person who has a visual impairment such as distance and near visual acuity, contrast sensitivity, and/ or visual fields. However, near vision and reading ability are often the most affected (Dickinson 1998, Rubin 2013). Management modalities (e.g. aids/ devices, and rehabilitation and training) for people with a visual impairment vary according to the severity of visual impairment, the nature and cause of the underlying condition, the age of the patient, the extent of impact of visual impairment on visual-related tasks such as reading, and the available management options in a specific clinic (Freeman and Jose 1997, Freeman et al. 2007).

The goals of visual impairment management could include ,but are not limited to,: 1) improving visual acuity (at near and distance), 2) enhancing reading performance, 3) reducing the effect of photophobia, 4) improving patients' independence, and 5) enabling patients to perform daily tasks (Freeman and Jose 1997, Dickinson 1998, Freeman et al. 2007).

A brief description of the available management modalities (optical and non-optical low vision aids/ devices, sight substitution aids/ devices, patients training, and vision rehabilitation) for patients with a visual impairment follows; classified according to the aim/ objectives of use. Electronic low vision aids/ devices descriptions are covered in more details in section 2.6.2.

2.6.1. Low vision aids/ devices

There are a variety of devices/ aids available for people with a visual impairment, and there are different ways of classifying or categorizing these devices. Classifications could be based on the aim of using certain devices such as improving contrast or visual acuity, or the technical characteristics of the devices. For example, Ilango (2003) has categorised low vision aids into optical and non-optical aids, as shown in Table 2.6.

Optical aids	Non-optical aids	Substitution aids
Telescopes	Large print books	Mobility canes
Aspheric lenticular spectacle lenses	Reading stands	Talking books
Hand magnifiers	Illumination devices	
Stand magnifiers	Writing devices	
Fresnel prisms	Medical devices e.g. insulin syringes with bold letters	
Prismospheres*		
Paper-weight magnifiers		
Bar magnifiers		
Pocket magnifiers		
Electronic aids e.g. CCTV systems		
Anti-glare glasses		

Table 2.6: Aids to enhance vision (adapted from Ilango, 2003). * A prismosphere is a prism with a spherical lens.

2.6.1.1. Optical aids to compensate for reduced distance visual acuity

Telescopes

Telescopes include optical systems for magnifying the apparent size of a distant object, which consists of an objective lens that forms a real image of the object and an ocular lens or eyepiece that magnifies the image formed by the objective (Freeman and Jose,

1997). Two main types of telescopes are available to people with a visual impairment these include hand-held or spectacle-mounted and they can be used monocularly or binocularly (Freeman and Jose 1997, Freeman et al. 2007, Schurink et al. 2011). Hand-held telescopes can be more convenient for short-term use such as spotting, and reading signs. Spectacle-mounted telescopes (full diameter, bioptic, reading or surgical) can leave hands free. Issues such as restricted field of view, weight and alignment should be considered when prescribing spectacle-mounted telescope (Cole 1993, Nowakowski 1994, Dickinson 1998, Freeman et al. 2007, Schurink et al. 2011).

2.6.1.2. Optical aids and devices to compensate for reduced near visual acuity

A range of optical magnifiers are available, and are used to enlarge and enhance viewing of a near task such as reading a text, these include:

High addition spectacle lenses

Spectacle-mounted reading lenses are high plus lenses (high plus lenses more than +3.00 dioptres/ high plus prescription relative to the patient's refractive error) that provide magnification from 1.5 to 6 times. They provide a wide field of view (Bailey 1979, Bither 1987, Cole 1991, Cohen and Waiss 1991, Williams 1991, Freeman and Jose 1997, Dickinson 1998). However, the higher the magnification, the shorter the working distance.

Near telescopes

Near telescopes and distance telescopes can be modified by adjusting focus or adding a reading cap in order to enhance near viewing. Compared to high addition plus lenses with equivalent power, they have a larger viewing distance, but a restricted field of view (Bailey 1981, Mancil 1986, Reich 1991, Cole 1996, Freeman and Jose 1997, Freeman et al., 2007).

Hand-held magnifiers

Hand-held magnifiers consist of a lens that gives a magnified image that is encircled by a lens holder with a handle (Freeman and Jose, 1997). Hand-held magnifiers can be used at different viewing distances; the magnification can be changed by changing the distance between the magnifier and the viewed object and/ or by changing the distance between the magnifier and the eye (Freeman and Jose 1997, Dickinson 1998, Freeman et al. 2007, Schurink et al. 2011). They can be useful for short term reading such as spot reading, reading a price labels, reading a telephone directory (Dickinson, 1998). The power range of hand-held magnifiers is 1.5-10 times. Versions of hand-held magnifiers are available with lights.

Stand magnifiers

Stand magnifiers can be controlled by hand for navigation while resting on the viewed object (Cole 1991, Freeman and Jose 1997, Dickinson 1998, Schurink et al. 2011). Stand magnifiers are mainly fixed focus, but in lower powers variable focus options are also available (Dickinson, 1998). Patients with difficulties holding objects often prefer the use

of stand magnifiers over hand-held magnifiers for reading because they do not need to find an appropriate distance as the lens-to-text distance is constant (Freeman and Jose 1997, Dickinson 1998, Freeman et al. 2007, Schurink et al. 2011). In fixed focus stand magnifiers, the lens to object distance can be less than the focal length of the lens. An example of the optics of the stand magnifier is described in Chapter 7 of this thesis. The power range of stand magnifiers is approximately 1.5-15 times, most of them have an illumination system.

2.6.1.3. Visual aids/ devices to compensate for visual field defects

Visual aids/ devices to compensate for defects in the peripheral visual field:

Patients with peripheral visual field defects find it more difficult to perform tasks that require navigation through the environment (Kuyk et al. 1996, Kuyk et al. 1998). Compensation for scotomas in the peripheral visual field can be achieved by training (e.g. visual scanning to improve patients ability to be aware of the surrounding), environment adaptations, prisms, mirrors, reversed telescopes, and negative lenses (Coeckelbergh et al. 2001, Anderson 2002).

Prisms

Prisms are used to displace the retinal image toward the prism apex. They are usually prism segments that are placed on the lens with the prism base towards the visual field defect, but off centre so a patient is unable to see it once in the primary gaze position

(Dickinson, 1998). Prisms that are used are Fresnel prisms and ground prisms within the lens (Dickinson 1998, Szlyk et al. 2005).

Mirrors

Mirrors are available either as clip-on devices or can be fixed to the spectacles (Cohen, 1993). Mirrors are placed on the same side of the affected visual field which helps to reflect the image from the non-seeing retina towards the intact retinal area (Bailey, 1982). These have proved to be useful for patients with hemianopia involving the temporal visual field but not for overall constriction of the visual field (Dickinson, 1998).

Reversed telescopes and minus lenses

Reversed telescopes and minus lenses enable patients to use their remaining visual field (Dickinson, 1998). They also increase the field of view, but make the image smaller (Dickinson 1998, Brilliant and Ginsburg 1999, Freeman et al. 2007).

2.6.1.4. Non-optical low vision aids

Non-optical aids are devices or appliances that enhance the independence of people with a visual impairment and improve their vision related tasks by using relative size magnification (i.e. enlarging the viewed object while maintaining the same viewing distance) or enhancing contrast, or substituation (Dickinson 1998, Freeman et al. 2007). These might be aids to improve the visibility of the retinal image (e.g. writing frames), or aids that optimise the use of magnifiers (e.g. maintaining a fixed distance between magnifier and object) (Dickinson, 1998). Examples of the non-optical low vision aids

include large print texts, bold-lined papers, fiber-tip pens, reading stands, and typo-scopes, etc. (Dickinson, 1998).

Enhancing contrast and reducing glare

For people with a visual impairment, lighting is considered a critical factor to achieve the optimum level of visual functions (Dickinson, 1998). Functional performance of daily activities, such as reading, face recognition and mobility, in people with a visual impairment is limited once contrast sensitivity is reduced (Marron and Bailey 1982, Peli et al. 1991, Whittaker and Lovie-Kitchin 1993, Peli 1994, Leat and Woo 1997, Dickinson 1998, Kuyk et al. 1998, West et al. 2002, De-Boer et al. 2004). Also, patients' visual comfort when carrying out different vision related tasks is affected by glare sensitivity (Waiss and Cohen, 1991).

Different management options can be employed to reduce the effect of glare sensitivity and reduced contrast sensitivity. These include adjusting the light level for optimum viewing, using filters, electronic low vision aids, and using non-optical aids (e.g. hats, typoscopes, and side shields) (Rosenberg 1984, Lawton 1989, Waiss and Cohen 1991, Peli et al. 1991, Peli 1994, Dickinson 1998, Freeman et al. 2007).

2.6.1.5. Sight substitution aids/ devices

These include aids/ devices that assist patients with a visual impairment to use other senses than vision. These include auditory devices such as talking watches, talking books, voice activated typewriters or audio materials; tactile aids such as Braille code

books, drug box labels or watches; and mobility devices such as guide dogs or mobility canes (Cook and Polgar, 2012).

2.6.2. Electronic low vision aids

'Closed Circuit Televisions' (CCTVs) was the first term that has been used to describe electronic low vision aids (Kay, 1984). Electronic devices (also called electronic magnifiers, video magnifiers, closed circuit television systems CCTVs (Kay, 1984), and electronic vision enhancement systems (EVES) (Wolffsohn and Peterson, 2003) are devices that incorporate a video camera, a display screen, lenses and digital magnification. These devices allow people with a visual impairment to put reading material or objects to be viewed under the camera and then the formed image of the viewed object is displayed on an electronic display screen that could be a computer screen or a standard television screen (Kay 1984, Wolffsohn and Peterson 2003). Throughout the text, they will be referred to as 'Electronic low vision aids', unless necessary to use another term.

Electronic low vision aids are an important potential management option for patients with a visual impairment. They have the potential to provide more features and greater flexibility compared to conventional low vision aids aids such as hand-held or stand magnifiers, and telescopes (Kay 1984, Wolffsohn and Peterson 2003). An electronic low vision device provides a wide range of magnification, contrast manipulation, colour change ability, auto and variable focus, and a larger field of view (if they have a large display screen) (Kay 1984, Wolffsohn and Peterson 2003).

2.6.2.1 The history of the development of electronic low vision aids

Wolffsohn and Peterson (2003) reviewed the 'current knowledge of Electronic Vision Enhancement Systems (EVES)'. The review includes classification, hardware, and software, development of technology, magnification, the size of field of view, contrast and the enhancement of the image. They also reviewed the devices from the users' perspective for example usage of the devices including the speed and duration of reading, and the training required. In addition, they highlighted the potential for future development (Wolffsohn and Peterson, 2003).

Electronic low vision aids incorporate the concept of 'transverse magnification' which was firstly conceived to be incorporated in the application of low vision aids in the 1950s (Potts et al. 1959, Wolffsohn and Peterson 2003). They were introduced in the 1970s (Fletcher 1979, Wolffsohn and Peterson 2003), however they were firstly described in 1959 (Potts et al., 1959).

In 1969, Genensky described modifications, for example, variable magnifications, reverse contrast, a 'Gestalt system' (to provide a wider field of view, with a small area of interest magnified), high-speed line return and self-focusing (Genensky 1969, Wolffsohn and Peterson 2003). However, due to limited technology development such as lack of portability, higher cost, and electrical faults (Goodrich et al., 1976) electronic low vision aids have not been commonly used or prescribed until recently (Wolffsohn and Peterson, 2003). Goodrich et al. (1976) reported that one third of EVES developed electrical faults after 2 to 4 years of use; however these faults were often easily rectified.

It was predicted in the 1980s that electronic low vision aids would become more important in the rehabilitation of patients with a visual impairment (Brown, 1981). Mouse-style electronic low vision aids (a computer mouse-like unit with a camera incorporated within it) were firstly described in the 1970s (Fletcher, 1979). Recently, Harvey (2004) and Macnaughton (2005) suggested that the use of electronic magnification in low vision for all age groups should be considered.

2.6.2.2. Classifications of electronic low vision aids

Electronic low vision aids are available as hand-held, mouse operated, head-mounted or stand-mounted devices. The common features of these devices include a video-camera, a monitor (a display unit), and an illumination system. If they are stand-mounted devices they will include an XY-table to position books on (Schurink et al., 2011). Stand-mounted electronic aids work by electronically magnifying the viewed object, and are usually used to improve reading (Schurink et al., 2011). Books have to be placed on the adjustable table to enhance reading, the magnified image of a book or text is displayed on a monitor (e.g. television screen) (Schurink et al., 2011).

Hand-held electronic low vision aids can come on rollers that make it easy to move them on a flat surface (Schurink et al., 2011). In mouse operated devices there is a computer mouse with an electronic camera that records the image; the image is then presented on a computer screen (Schurink et al., 2011).

Different classifications have been developed for electronic low vision aids. Figure 2.2 describes the classification of electronic low vision aids, according to Wolffsohn and Peterson (2003)**.** In the USA, electronic aids can be classified into two major categories, these include devices in which the camera and/ or display are mounted on a stand and devices that incorporate a hand-held camera (in other words, stand electronic devices and hand-held electronic devices). Stand-mounted devices were subdivided into in-line or side-by-side configuration, and other features including colour options and magnification ranges were listed. Hand-held systems were sub-divided into small or normal size displays, and head-mounted displays (Uslan et al., 1996).

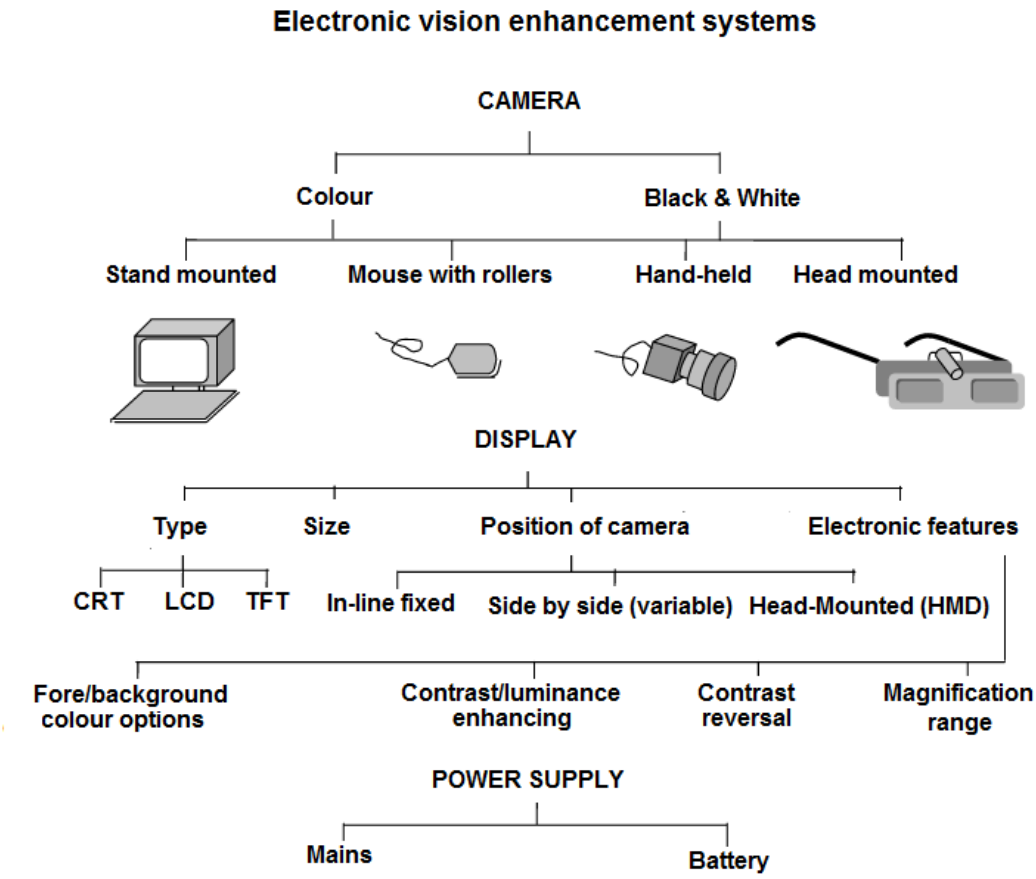


Figure 2.2: Classification of electronic low vision aids. CRT: Cathode Ray Tube, LCD: Liquid Crystal Display, TFT: Thin Film Transistor (Wolffsohn and Peterson, 2003).

Currently, there is a variety of electronic low vision aids. This might be because of the increased demand for these devices, due to the improvement and the simplicity of currently available devices (Wolffsohn and Peterson, 2003). The American Foundation of the Blind (2010) described five main types of electronic low vision aids these include: 1) desktop (Figure 2.3), 2) flex-arm camera (Figure 2.4), 3) head-mounted display (Figure 2.5), 4) hand-held camera to TV (Figure 2.6), and 5) pocket and portable models (Figure 2.7).

Desktop video magnifiers (Figure 2.3) consist of a computer screen, a video camera, a variable contrast control, a moveable platform (14x16 inches) and an illumination source (The American Foundation of the Blind, 2010). The viewed object/ text should be placed on the platform under the camera while the individual is watching the display screen. Desktop video magnifiers enable features such as automatic and manual focus, contrast reverse, magnification range from 3x to > 60x, and adjustment of magnification, brightness, contrast and colour (The American Foundation of the Blind, 2010). They have some limitations such as lack of portability (Harper et al., 1999), and platform manipulation restrictions. Locating the beginning and the end of a line on reading text was solved by adding a 'margin stop' (The American Foundation of the Blind, 2010). The approximate cost of a desktop video magnifier is £1,252-£2,192 (The American Foundation of the Blind, 2010).

Figure 2.3: A desktop electronic magnifier (Merlin LCD desktop electronic magnifier/ Enhanced Vision – USA, cost: £1,766). It has a display screen and a moveable reading table (platform) (Enhanced Vision, 2015).

Flex-arm video magnifiers (Figure 2.4) are similar to desktop video magnifiers, but the video camera is housed in a flexible (moveable) arm (The American Foundation of the Blind, 2010). Flex-arm video magnifiers have similar features to desktop magnifiers such as variable magnification controls, contrast enhancement and reversal controls, etc. But they do not have the X-Y table so they can be more difficult to use, and are also not portable (The American Foundation of the Blind, 2010). They are cheaper than desktop electronic magnifiers, with approximate cost of £1,252-£1,879 (The American Foundation of the Blind, 2010).

Figure 2.4: A flex-arm electronic magnifier with a computer display and a camera housed in a flexible arm (Acrobat HD ultra-long arm/ Enhanced Vision – USA, cost: £1,307) (Enhanced Vision, 2015).

Head-mounted video magnifiers (Figure 2.5) incorporate a display that is mounted on a unit worn on the patient's head (The American Foundation of the Blind, 2010). The magnification of the image displayed on the head-mounted display can be manipulated until the patient finds the required magnification (The American Foundation of the Blind, 2010). Head-mounted video magnifiers have features such as colour mode, high contrast and contrast reverse viewing modes, and distance and near viewing (The American Foundation of the Blind, 2010). They are limited by being large and heavy, have a poor appearance, provide only low resolution and require the user to move the camera over the viewed object. This can be problematic for people with physical limitations, motion sickness, and claustrophobia (Culham et al. 2004, The American Foundation of the Blind 2010, Schurink et al. 2011). The approximate cost of a head-

mounted video magnifier is £1,565-£2,192 (The American Foundation of the Blind, 2010).

Figure 2.5: A head-mounted electronic low vision aid with camera incorporated on a head-mounted unit (Jordy head-mounted electronic magnifier, Enhanced Vision – USA, cost: £1,831) (Enhanced Vision, 2015).

Mouse video magnifiers (Figure 2.6) include a computer mouse-like unit with a camera incorporated within it connected to a display screen. The mouse-like unit can be moved over the viewed object (The American Foundation of the Blind, 2010). Features of mouse video magnifiers include high contrast and contrast reverse viewing modes (The American Foundation of the Blind, 2010). Limitations of these magnifiers include less adjustable features such as magnification and image characteristics (The American Foundation of the Blind, 2010). The approximate cost of a mouse video magnifier ranges from few hundred pounds to £1,879 (The American Foundation of the Blind, 2010).

Figure 2.6: A mouse video magnifier. The camera is incorporated within the mouse that can be attached to a computer or TV screen [Max mouse electronic magnifier, Enhanced Vision – USA, cost (not including the screen): £125] (Enhanced Vision, 2015).

Pocket and Portable video magnifiers (Figure 2.7) are very small, light-weight electronic pocket-size magnifiers which have been developed recently. Features of pocket and portable electronic video magnifiers include adjustable magnification (up to 42x), autofocus, high contrast, contrast and colour manipulation, snapshot, and chargeable batteries. Pocket and portable video magnifiers are limited when reading longer passages (The American Foundation of the Blind, 2010). The approximate cost of these magnifiers ranges from £100 to £1,252 (The American Foundation of the Blind, 2010).

Figure 2.7: A pocket and portable electronic magnifier. It has a small display screen with few buttons (Amigo portable electronic magnifier, Enhanced Vision – USA, cost: £930) (Enhanced Vision, 2015).

Other electronic devices such as electronic book-readers (e.g. Kindle, and Amazon readers) (Figure 2.8), i-Pads, i-phones or tablets can be used as portable magnifiers as they can enhance and magnify the viewed objects (The American Foundation of the Blind, 2010). Features of electronic book-readers include internal memory that can hold from 150-2000 full-text novels, a text-to-speech option, and a flexible active matrix ink display that consists of the electronic paper which has a wide viewing angle of almost 180 degree (Chen et al. 2003, Crossland et al. 2010, The American Foundation of the Blind 2010). However, electronic book-readers are limited by low contrast (about 60% Michelson contrast) and a slow refresh rate of approximately 250 ms (Crossland et al., 2010).

Figure 2.8: Kindle (Kindle, USA) and Sony (Sony Corporation, Japan) readers (Mariosundar, 2007).

2.6.2.3. Advantages and disadvantages

Electronic low vision aids have been considered more user-friendly and interactive than conventional optical devices. The advantages of using electronic low vision aids for people with a visual impairment, in general, compared to conventional low vision aids such as hand-held/ stand magnifiers, include the following: 1) larger field of view, 2) large magnification range, 3) magnification can be manipulated according to user's requirements and comfort, thus in a later stage of the disease in which a patient might need different magnification, the device can still be used (Goodrich et al., 1980), 4) provide adjustable features such as balck-on-white and white-on-black viewing modes, brightness, and colours, 5) enable freeze frame feature, 6) more comfortable posture; they have flexible focus (some PELVAs can be used at variable distances), 7) maintain binocularity , and 8) they are easy to operate (few buttons to switch on/ off and to

manipulate zoom and luminance) (Mehr et al. 1973, Kay 1984, Uslan et al. 1996, Harper et al. 1999, Wolffsohn and Peterson 2003, Culham et al. 2004, Schurink et al. 2011).

In comparison, magnification cannot be adjusted and contrast cannot be manipulated in optical low vision aids. Therefore, patients with a visual impairment may require more than one device to accomplish the list of tasks that they may require to do during the day, or in the later stages of the disease they might need additional devices or to replace the existing ones (Culham et al., 2004). Also, as the magnification increases, aberration increases and field of view constricts (Culham et al., 2004).

On the other hand, the disadvantages of electronic low vision aids include; neck and back-pain which might be experienced by some users (Zabel et al. 1982, Wolffsohn and Peterson 2003). Goodrich et al. (1976) reported that one third of electronic low vision aids developed electrical faults (Wolffsohn and Peterson, 2003).

Optical magnification is achieved by the optics of lenses where a viewed object appears closer or bigger, whereas digital magnification is achieved by making parts (pixels) of an image appear larger (similar to zoom-in for an image on a computer screen) (Perlman, 2011). The image quality using digital magnification may not be as good as image quality using optical magnification (Perlman, 2011). When using digital magnification, the new enlarged image is based on the same number of pixels; also the image quality might be worse with digital magnification at higher zoom levels, although optical aberration is a downside of optical magnification (Dickinson 1998, Perlman 2011).

Culham et al. (2004) suggested that ideally, electronic aids should provide a wide and a continuous range of magnification. Moreover it has to facilitate the manipulation of image quality factors such as contrast and brightness. It would be also important for the ideal electronic visual aid to be light-weight, portable, cosmetically acceptable, and easy to use (Culham et al., 2004).

2.6.3. Patient's training and education

'In-office training' is important for patients to be familiar with the device(s) they have been prescribed, in terms of how they should be used and the limitations that they might encounter once they use the prescribed devices (Goodrich 1997, Freeman and Jose 1997, Dickinson 1998). Some optical low vision aids might be more complex to use and they may require additional training, to make sure that patients are able to use these devices (Goodrich 1997, Freeman and Jose 1997).

The visual performance of people with a visual impairment could be improved with practice and training on the use of the devices. Training was found to be helpful in improving reading speed and duration (Dickinson 1998, Nilsson et al. 1998, Backman 1999, Nilsson et al. 2003, Kuyk et al. 2008). Also, patients' preference or satisfaction with the devices may change after using them for everyday tasks (Spitzberg and Goodrich, 1995). Training also may be useful in some cases in which patients are required to efficiently use their residual vision, for example by using eccentric viewing, fixation, scanning, and saccade and pursuit eye movements etc. (O'Connell 1996, Waiss and

Cohen 1996). Kuyk et al. (2008) and Culham et al. (2009) found that home experience of the prescribed devices could be beneficial for users to have a perspective on the practicability of using the device for a range of tasks and it could provide realistic expectations of what can be achieved.

2.6.4. Visual rehabilitation

Low vision rehabilitation services can be defined as *"a rehabilitative or habilitative process, which provide a range of services for people with low vision to enable them to make use of their eyesight to achieve maximum potential"* (Low Vision Services Consensus Group, 1999). 'Habilitative' means that people with visual impairment learn new skills that they have not acquired before (Low Vision Services Consensus Group, 1999). 'Rehabilitative' means that people who have lost the ability to do some skills due to visual impairment are rehabilitated in order to enable them to resume doing these tasks (Low Vision Services Consensus Group, 1999).

Rehabilitation services can be standard hospital-based services provided by optometrists, or low vision therapists (Virtanen and Laatikainen 1991, Crossland et al. 2007, Binns et al. 2012), and/ or multidisciplinary services where additional services can be provided by other health professional such as occupational therapists, mobility and training specialists (McCabe et al. 2000, Haymes et al. 2001, Lamoureux et al. 2007, Stelmack et al. 2008), psychologists (Needham et al., 1992), in association with social services (Binns et al., 2012).

Low vision rehabilitation has been found to be effective to improve visual functions and quality of life (Stelmack et al. 2006, Stelmack et al. 2007, Lamoureux et al. 2007, Stelmack et al. 2008, Binns et al. 2012, Ryan et al. 2012, Stelmack et al. 2012). However, other studies found that low vision rehabilitation did not improve visual functions or quality of life (Scott et al. 1999, Reeves et al. 2004, De-Boer et al. 2006).

Ryan et al. (2012), found a significant reduction in self-reported visual disability, between baseline and 18 months post intervention by −0.28 logits (IQR −1.24 to 0.52), of patients with a visual impairment who attended low vision rehabilitation services in 180 optometry practices in Wales. This was less than that found between baseline and 3 months; −0.61 logits (IQR −1.81 to 0.02) post intervention (Ryan et al., 2012). The authors also found that there was a decrease in patients' satisfaction with the low vision aids 18 months after intervention (Ryan et al., 2012).

Outcomes of the Veterans Affairs Low Vision Intervention trial suggested that low vision rehabilitation with the Veterans Affairs Low Vision service significantly improved visual functions including reading ability, visual information processing, mobility, and visual motor skills (Stelmack et al., 2008).

2.7. Prescribing patterns for low vision aids

Very few studies have assessed the prescribing patterns for low vision aids, particularly as new emerging technology impacts on low vision practice.

Crossland and Silver (2005) aimed to determine the types of low vision devices prescribed by clinicians in the low vision clinic at Moorfield Eye Hospital in London and to investigate changes in the prescribing habits over a 30 years period from 1973 until 2003. They reported that the median age of patients attending the clinic did not change significantly over this period. Eighty four percent of the patients who attended the clinic for the first time were prescribed at least one low vision device (Crossland and Silver, 2005). The devices that were more frequently prescribed for new patients included: non-illuminated hand magnifiers, illuminated hand magnifiers, and illuminated stand magnifiers (Crossland and Silver, 2005). Between 1973 and 2003, there was a linear increase in the number of the prescribed hand magnifiers and a corresponding decrease in the number of prescribed near spectacle mounted telescopes (Crossland and Silver, 2005). According to the authors, this could be due to the increased availability of electronic magnifiers, and the development of illuminated hand magnifiers (e.g. LED illumination and a higher range of magnification). The authors also found that even though there was a decline in the number of prescribed non-illuminated hand magnifiers, they contributed to a larger portion of the prescribed devices, particularly when compared to spectacle mounted telescopes; which might be due to the fact that spectacle mounted telescopes are more expensive than the non-illuminated hand-held magnifiers (Crossland and Silver, 2005). CCTVs were not included in the study, because the hospital did not provide these devices to patients, however clinicians did explain the use of CCTVs and they provided information about CCTVs suppliers (Crossland and Silver, 2005). CCTVs were provided for school-children by local education authorities. Figure

2.9 shows the low vision aids that were included in the Crossland and Silver study and the differences in the prescription patterns over a 30 years period (1973-2003).

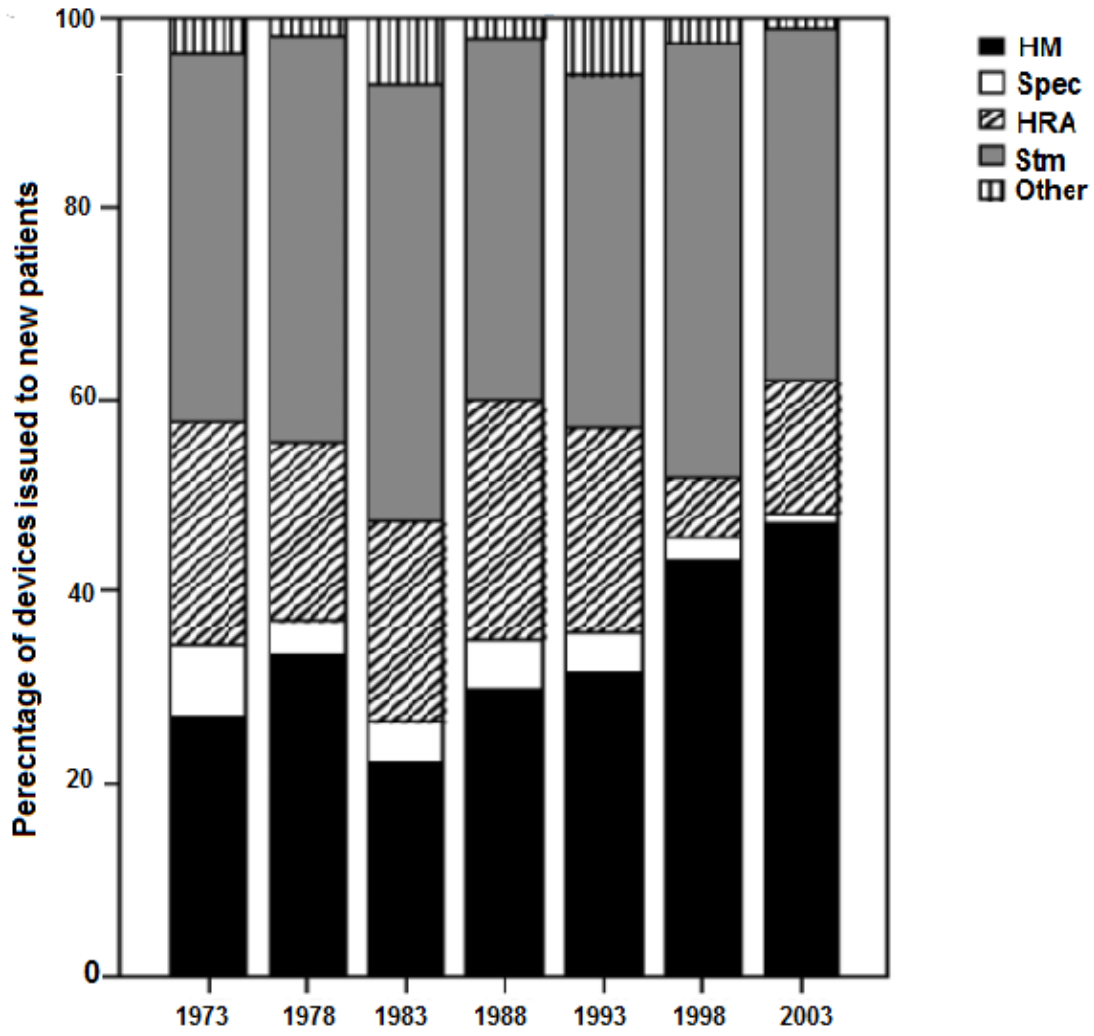


Figure 2.9: The prescription pattern of low vision aids between 1973 and 2003. (Crossland and Silver, 2005) HM: Hand Magnifiers, Spec: Spectacle Mounted, HRA: High Reading Addition, Stm: Stand Magnifiers.

Nguyen et al. (2009), in a Low Vision Clinic and Research Laboratory-Germany, reported that visual rehabilitation was achieved mostly by optical low vision aids (58% of study subjects) and less by electronic low vision aids (42% of patients). These findings are

significantly different to the results obtained by Crossland and Silver (2005). The National Health Scheme did not provide electronic devices for low vision patients in England. So, Nguyen et al. (2009) results may represent the prescription pattern in a private eye clinic.

Results from the Lighthouse National Survey on Vision Loss (1995), in the USA, showed that of study populations of those aged 45 years and older; 30% of people with self-reported visual impairment used optical visual aids such as magnifiers or telescopes, whereas 21% used large print texts, and less than 5% used adaptive visual aids such as talking books and clocks (Lighthouse National Survey on Vision Loss 1995, Jutai et al. 2005). However it is not clear whether electronic low vision aids were included.

Even though there are several types of electronic low vision aids, prescribing for children with visual impairment is considered limited (Corn et al. 2002, Leat 2002, Ruddeck et al. 2004, Lennon et al. 2007, Haddad et al. 2009, Schurink et al. 2011).

2.8. Effectiveness of low vision aids for people with a visual impairment

Currently, there are a variety of optical and electronic low vision aids. With the development of different low vision aids, there might be important changes in the trends or approaches to prescribing. The increased demand for electronic vision aids and the simplicity of these devices have increased the likelihood that they will be considered in clinical practice (Wolffsohn and Peterson, 2003). The most appropriate device is the device which meets patient's goals and objectives, and improves functional

abilities. Thus, it might be difficult to find the most appropriate low vision aid for a particular patient with visual impairment. A patient may require more than one device to accomplish the required list of tasks that they may require to do during the day, or in the later stages of the disease they might need additional devices or to replace the existing ones (Culham et al., 2004). “In the absence of adequate assessment of visual function, the choice of rehabilitation options has depended heavily on trial and error with different devices and interventions. Although trial and error might be expected to lead eventually to an adequate solution, trials consume time, require a large inventory of expensive devices, and frustrate clients” (Whittaker and Lovie-Kitchin, 1993).

The effectiveness of different low vision aids has been evaluated in different studies based on the improvement of clinical visual factors (e.g. visual acuity, and contrast sensitivity), the improvement of functional abilities, the improvement of perceived quality of life and patients’ satisfaction, the devices’ characteristics (e.g. magnification) and improvements in reading performance (e.g. rate, duration and comprehension) of people with a visual impairment (Brown 1981, Whittaker and Lovie-Kitchin 1993, Beckmann and Legge 1996, Watson et al. 1997, Lovie-Kitchin et al. 2000, Dickinson and Fotinakis 2000, Culham et al. 2004, Stelmack et al. 2006, Culham et al. 2009, Nguyen et al. 2011, Rubin 2013). People with a visual impairment particularly those who have difficulty or inability to read because of vision loss tend to use devices that improve their reading performance.

There have been very few publications regarding the effectiveness of pocket and portable electronic low vision aids (PELVAs), and there is no literature available (to our knowledge) that evaluates the accuracy of electronic low vision aids parameters (e.g. magnification, resolution and contrast sensitivity). Bullimore and Bailey (1989) reported that manufacturers' specifications in terms of optical parameters of stand magnifiers may not necessarily be accurate, also Bailey et al. (1994) advised that both the equivalent power and the image location should be verified to achieve the most appropriate prescription (Bullimore and Bailey 1989, Freeman et al. 2007). Moreover, many companies that sell electronic devices may not have a background in low vision rehabilitation (Wolffsohn and Peterson, 2003). The next section highlights the prescription patterns of different low vision aids, and it summarises the available literature about the effectiveness of low vision aids in improving the abilities of people with a visual impairment; however there will be more emphasis on reading performance.

To our knowledge, little has been published regarding the efficiency of different low vision devices or interventions, very few studies compared electronic low vision aids with conventional low vision aids aids such as hand-held/ stand magnifiers, and very few studies compared different electronic low vision aids. Peterson et al. (2003) compared the effect of three different electronic vision enhancement systems (EVES) ('mouse-based EVES with monitor viewing', 'mouse-based EVES with head-mounted display (HMD) viewing', and 'stand-based EVES with monitor viewing') and optical magnifiers on near task performance for people with a visual impairment. They compared different

visual tasks which include reading speed, reading acuity, time taken to track between columns of print, following a route map, locating a specific feature, and identification of specific information from medicine labels (Peterson et al., 2003).

Peterson et al. (2003) found that: 1) reading speed using all of 'mouse-based EVES with monitor viewing', 'mouse-based EVES with HMD viewing', and 'stand-based EVES with monitor viewing' was faster compared to optical magnifiers, 2) reading speed using 'stand-based EVES with monitor viewing' was higher compared to 'mouse-based EVES with HMD viewing', 2) the column location task was faster using optical magnifiers compared to the three types of EVES, 3) the map tracking and identification of medicine labels was slower using 'mouse-based EVES with HMD viewing' compared to other devices (Peterson et al., 2003). The authors concluded that although electronic low vision aids could provide objective advantages to people with a visual impairment such as in reading speed and acuity as well as some near tasks, some of them can perform no better than optical low vision aids.

The authors found that previous experience of using EVES had no effect on the performance when undertaking visual tasks (reading speed, column location task, map tracking, or identification of medicine labels), but patients with previous experience of these devices found it easier to use optical magnifiers compared to patients with no previous EVES experience (Peterson et al., 2003). Previous optical magnifiers experience had no significant effect on reading speed, column location task or map tracking, but patients with previous experience of these device were slower at identification of

medicine labels compared to patients with no previous experience (Peterson et al., 2003).

Culham et al. (2004) studied the clinical performance of electronic head-mounted devices (Jordy (Enhanced Vision, USA, http://www.enhancedvision.com), Fliperport (Enhanced Vision, USA, http://www.enhancedvision.com, Maxport (Enhanced Vision, USA, http://www.enhancedvision.com, and NuVision (Keeler Limited, UK, http://www.keeler.co.uk). A head-mounted device is shown in Figure 2.5. They aimed to compare the 'laboratory based clinical measurements' and practical visual tasks among 20 people with macular degeneration. They measured near visual acuity using a Bailey-Lovie near acuity chart, intermediate visual acuity using a Bailey-Lovie near acuity chart fixed at 2/3 metres, and distance visual acuity using an Early Treatment Diabetic Retinopathy Study (ETDRS) Log MAR acuity chart at 4 metres. Contrast sensitivity was assessed using a Pelli-Robson chart at 1 metre. Visual task assessments included performance at writing a cheque, reading three different text sizes (N5, N10, and N20) using passages of text, and identifying grocery items on a shelf. After initial evaluation each patient took home two devices (randomly selected) for two weeks. After home-loan of devices patients were evaluated for reading performance. Culham et al. (2004) reported that generally none of the four devices stood out as the best device. However 1) Flipperport and Jordy provided better distance and intermediate visual acuities compared to previously prescribed optical low vision aids, 2) for all devices in this study, near acuity and contrast sensitivity were similar to that with optical low vision aids, 3) practice at home improved the performance, 4) optical low vision aids were the best

devices for the majority of tasks, and 5) younger patients and people with better distance visual acuity were found to be more likely to benefit from the use of head-mounted devices compared to optical low vision aids particularly in reading small print.

The authors also tried to correlate users' opinions with patients' performance of the devices (using VF-14 modified questionnaires to evaluate patients' performance) (Culham et al., 2009). During the laboratory assessment, the Flipperport was the best device overall in terms of: rating, the score of image quality and the ability to magnify, but after home loan there was no significant difference between the four devices. Authors reported that the comfort of device was important, but it was not predictive of rating the device if the magnification was taken into account (Culham et al., 2009).

In this study, the actual performance of devices for patients was measured by reading speed (Culham et al., 2009). However authors found that patients' impression or satisfaction of a given device was affected by a number of factors such as performance, ergonomics, cost, size, weight, appearance, portability, ease of use of controls of the devices, age of users, type of diagnosis, and time since diagnosed with vision loss (Culham et al., 2009).

Culham et al. (2009) found that home experience of the prescribed devices could be beneficial for users to have a perspective on the practicability of using the device for a range of tasks and it could provide realistic expectations of what can be achieved. However, they suggested that extensive training is not necessary for the users to begin

to manage using devices alone, but continuous support and training at home may impact on the users experience, satisfaction and ability in addition to the final decision of clinicians. Goodrich et al. (1977) found that practice and training for CCTVs over a period of 10 days improved reading speed and the duration of using devices; this might be because not too many people were aware of using computer technology at that time (Culham et al., 2009). Culham et al. (2009) found also that more success with EVES was noticed in younger patients and patients who have been recently diagnosed with an eye disease or disorder.

Goodrich and Kirby (2001) conducted a study that aimed to provide comparative information for practitioners to assist patients to select the most cost-effective reading devices. They compared reading speed and duration, and subjects' preference for two types of CCTVs with optical devices. They found that reading speed and duration were greater with CCTV systems than optical devices, but they did not find a significant difference in the performance between the two types of CCTVs. Patients preferred the stand-mounted system, but when they were asked to take the device price into consideration their preference were equal for both CCTV systems. The authors concluded that clinicians could expect better initial reading performance for patients with central visual field defects when reading with CCTVs compared to optical devices. They also found that hand-held CCTVs are less expensive than stand-mounted systems however the hand-held CCTVs had a lower subjective preference rating, but provide equal performance (Goodrich and Kirby, 2001).

Optical low vision aids are highly task-specific (e.g. devices for improving distance vision only such as telescopes, and devices for improving near visual acuity only such as magnifiers), that means a low vision patient could require more than one optical device in order to meet his/ her objectives of seeking low vision services (Culham et al., 2009). Studies indicate that at least 80-91% of patients attending low vision services were provided with a low vision aid (Leat et al. 1994, Shuttleworth et al.1995, Watson et al. 1997, Harper et al. 1999). However some patients discontinue the use of low vision devices after prescription (Leat et al. 1994, Watson et al. 1997, and Harper et al. 1999). Causes that could make patients discontinue the use of the prescribed devices include: 1) changes of their vision, 2) the ergonomic of the device, 3) frustration with limitations imposed by the use of optical devices where patients try to find another device (Watson et al. 1997).

It has been found that patient's age and the visual acuity achieved with devices are not predictive of the continued use of low vision aids (Leat et al. 1994, Watson et al. 1997, Harper et al. 1999). A smaller group of patients wanted low vision devices to be less noticeable (Harper et al., 1999). Watson et al. 1997 suggested that patients would like to see a range of improvements in low vision aids such as wider field of view, higher resolution, automatic focus, additional image brightness, and clear near and distance view.

Harper et al. (1999) reviewed and described the new devices (i.e. electronic) and discussed their current and future potential in comparison with conventional low vision

aids. However, the authors explained that comparing patients' performance with conventional low vision aids and CCTVs is difficult, because not all patients are equally familiar with both types of devices.

Goodrich et al. (1980) tested 96 US veterans who had been CCTVs users for two years. They found that 50% of their patients use both types of devices (optical and CCTVs) in combination. The optical aid is used to find a specific item and the CCTVs for detailed viewing. Conventional aids were useful in "spotting" tasks or in cases where portability is important. When comparing the reading speed using the two types of devices, there was no difference however the duration of use was three times longer with CCTVs (Goodrich et al., 1980). Therefore this suggests that CCTVs should be considered when prescribing for longer reading tasks.

Harper et al. (1999) suggested that the measurement of dynamic visual acuity is important because it measures the effectiveness of retinal image stabilization and gaze stability in all planes of head movement. Dynamic visual acuity is the threshold of visual resolution achieved during relative motion of the visual target or the observer head. It is a measure of visual vestibular interaction (Demer and Amjadi, 1993). All spectacle mounted telescopes caused a decrease in dynamic visual acuity, regardless of their magnification (Demer and Amjadi, 1993).

Harper et al. (1999) suggested that it remains a priority to identify patients' factors that predict successful use of devices. For example, Whittaker and Lovie-Kitchin (1993) found

that the image contrast should be 10 times more than the patient's contrast threshold in order to increase reading speed to a level called "read for pleasure" i.e. high fluent reading (174 words/ minute).

Li et al. (2002) aimed to study the clinical effectiveness of optical and video low vision aids and to analyze the characteristics of the people with a visual impairment at Chang Gung Memorial Hospital low vision clinic. The sample included 203 patients who were evaluated for improvement in near and distance visual functions when using low vision aids. Spectacles were only able to meet both near and distance visual requirements in 21 patients, but 3 of them were prescribed Fresnel prisms with their spectacles. Eighty four of 121 patients with distance visual requirements benefited from telescopes. Only one patient benefited from adding a Jordy head-mounted device (Li et al., 2002), 118 out 136 patients who could not read newsprint, benefited from optical magnifiers, and 125 benefitted from using a MagniCam CCTV (Li et al., 2002). They concluded that low vision patients could benefit from video magnifiers if optical low vision aids failed to improve their vision. However, they reported that their patients can accomplish their tasks using traditional low vision aids (Li et al., 2002).

Also, the authors found that older patients preferred simple rather than complex low vision aids. This might explain why 82% of study subjects preferred optical low vision aids (Li et al., 2002).

2.9. Reading performance: Factors affecting reading performance with low vision aids

Reading difficulty is the most common complaint in people with visual impairment (Rubin, 2013). Rubin (2013) found that reading difficulty was the reason for 60% of patients to be referred to low vision practices. Literature available about the effectiveness of low vision aids has focused on improvement in reading ability or speed (Rubin, 2013). This was done by comparing the reading ability and/ or performance (e.g. critical print size, reading acuity and reading speed) with and without visual aids.

Reading tests such as the Minnesota Low Vision Reading Test (MNREAD) (Mansfield et al. 1993, Ahn et al. 1995, Ahn and Legge 1995, Mansfield et al. 1996, Rubin 2013), the Neale Analysis of Reading Ability (Revised British Edition), the New Reading Analysis (Neale 1989, Bowers 2000), the International Reading Speed Text (IReST) (Hahn et al. 2006, Ramulu et al. 2013, Rubin 2013), the Bailey-Lovie near acuity chart (Bailey and Lovie, 1980), the Colenbrander mixed contrast cards (Dexl et al., 2010), the sustained reading performance test (Ramulu et al., 2013) and text passages for reading such as the Flesh Kincaide Scale (Dickinson and Shim, 2007), etc. are often used in such studies (Schurink et al., 2011).

The Bailey-Lovie near reading chart is widely used to measure the acuity threshold which can be used to determine the magnification level that is required for reading print of any given size (Bailey and Lovie 1980, Rubin 2013). The letter size is decreased by a constant percentage on the following line. The text size is specified in Log MAR units (Bailey and Lovie 1980, Rubin 2013).

The Colenbrander mixed contrast card consists of high contrast and low contrast lines. The size of letter in each line decreases by a constant ratio (Dexl et al., 2010). The importance of the Colenbrander chart is that the test can be used to screen for reduction in both contrast and reading (Rubin, 2013).

The MNRead test is a continuous-text reading acuity chart. Each sentence consists of 60 characters, the sentences decreases in size by 0.1 log unit (Legge et al. 1989, Rubin 2013). The advantage of using the MNRead test is the fact that all of reading acuity, critical print size, and reading speed can all be measured using one chart. It is also available in different languages. However, having only two charts per language makes sentences easier to remember if the test is required to be repeated, it also requires calibrating the external lighting (Rubin, 2013).

The IREST is available in different languages; the English version consists of 10 plates (about 170 words each, Times Roman 12 font) (Hahn et al. 2006, Trauzettel-Klosinski 2012, Rubin 2013). Having 10 plates (170 words each), enables the assessment of reading speed without repeating the passages (Rubin, 2013). The limitation of the IREST is that it is available in one size (Rubin, 2013).

Factors affecting reading performance in patients with a visual impairment:

From summary of the available literature regarding reading performance, it is clear that several factors may affect reading performance, or can be predictive of reading performance. The factors are as follows:

1) Age:

Akutsu et al. (1991) found that reading rate was lower for normally sighted older people compared to young people, for characters with angular sizes of < 0.3 degree and > 1 degree (Akutsu et al., 1991).The authors explained that this was attributed to reduced contrast and dynamic visual acuity, and oculomotor limitations due to ageing (Akutsu et al., 1991). On the contrary, some studies found that age was not predictive of reading performance (Cummings et al. 1985, Legge et al. 1992, Fletcher et al. 1999, Ergun et al. 2003, Sunness et al. 2007).

2) Ocular conditions:

Legge et al. (1992) found a slower reading rate in patients who had AMD compared to other conditions. Brown (1981) found that patients who had AMD needed more magnification and more time to recognize texts compared to cataract patients. In contrast, central visual field status and ocular media status were not predictors of reading speed (Ahn and Ledge, 1995). In older patients, glaucoma was associated with a lower reading speed (Ramulu et al., 2009). Mohammed and Omar (2011) found a lower reading speed in young patients (aged 13-19 years) with visual impairment (different ocular conditions) compared to a normally sighted age matched group.

3) Type of magnifier:

Nguyen et al. (2009) found that low vision aids (CCTVs and optical low vision aids) significantly improved reading ability, and no difference was found in reading ability between optical and electronic low vision aids. Reading ability was improved using low vision aids and there was no reported difference between a variety of low vision aids (Margrain 2000, Bowers 2000). On the contrary, Dickinson and Shim (2007) found a lower reading speed with low vision aids compared to reading speed without low vision aids in older participants (60 – 85 years old), but not in younger participants (18 – 30 years old). The authors reported that lower reading speed with low vision aids in older participants was not attributed to age, but it might be attributed to the poorer manual dexterity compared to younger participants. The authors did not report if there was any difference in reading speed with different types of low vision aids (Dickinson and Shim, 2007). Also, with low vision aids, there was no significant difference in reading speed between moving the magnifier and moving the text (Dickinson and Shim, 2007). Ahn and Legge (1995) found a lower reading speed with low vision aids however a higher reading speed was found with spectacle mounted magnifiers, then hand-held magnifiers, followed by CCTVs and then stand magnifiers. Beckmann and Legge (1996) reported that page navigation was more problematic with hand-held magnifiers and electronic vision enhancement systems. Cheong and Lovie-Kitchin (2007) found that with hand-held magnifiers and electronic vision enhancement systems few characters were visible which requires moving magnifiers between words in order to increase visibility. Peterson et al. (2003) found a higher reading speed with mouse and stand-mounted

electronic vision enhancement systems compared to the reading speed with optical magnifiers. The reading speed with stand-mounted electronic vision enhancement systems was higher compared to the reading speed with mouse electronic vision enhancement systems. Goodrich and Kirby (2001) reported a higher reading speed and duration with CCTVs compared to optical low vision aids. There was no difference in reading speed between CCTVs or mouse devices in patients with a visual impairment and the normally sighted (Harland et al., 1998).

4) Visual acuity:

Whittaker and Lovie-Kitchin (1993) found that when reading the print size needed to be larger than acuity threshold, and the effectiveness of a low vision aid depended largely on acuity reserve. The authors found that an acuity reserve of 1.5:1 was required for 'fluent' reading (88 words/ minute), and an acuity reserve of 3:1 was required for 'high fluent' reading (174 words/ minute). Lovie-Kitchin et al. (2000) found that near visual acuity was predictive of higher rauding rate (i.e. reading for understanding). 'Rauding' is derived from 'reading' and 'auding', which means to be attending to words and comprehending each consecutively encountered thought contained in the words (Carver 1985, Carver 1993). In other words, an individual should read each word to comprehend the complete thought of each sentence. Rauding rate is the fastest rate that an individual can accurately comprehend relatively easy material/ text (Carver 1985, Carver 1993). Rauding accuracy is the highest level of text difficulty that an individual can accurately/ correctly comprehend (Carver 1985, Carver 1993). Rauding efficiency is the ability to comprehend efficiently, i.e. the number of thoughts that can

be comprehended per the amount of time allowed for reading (Carver 1985, Carver 1993). Rauding efficiency (E) can be calculated by applying the equation (E = A*R), where A is the rauding accuracy, and R is the rauding rate (Carver 1985, Carver 1993).

Latham and Tabrett (2012) found that an acuity reserve of 2:1 was sufficient to achieve a reading speed of 118 words/ minute. The authors referred to the reading speed of > 80 words/ minute as fluent reading speed, and the reading speed of 133 words/ minute as the maximum reading speed. Harper et al. (1999) found that reduced visual acuity was associated with lower reading ability. On the other hand, visual acuity was not predictive of reading performance (Cummings et al. 1985, Legge et al. 1992, Fletcher et al. 1999, Ergun et al. 2003, Sunness et al. 2007).

5) Contrast:

Whittaker and Lovie-Kitchin (1993) found that, in patients with visual impairment, a letter contrast of less than 4 times the patient's contrast threshold impaired reading rate and accuracy, whereas a letter contrast of less than 10 times the patient's contrast threshold only reduced reading speed. A contrast reserve of 4:1 was required for 'fluent' reading (88 words/ minute), and contrast reserve of 10:1 was required for 'high fluent' reading (174 words/ minute) (Whittaker and Lovie-Kitchin 1993, Crossland et al. 2010). Whittaker and Lovie-Kitchin (1994) suggested that a letter contrast threshold of higher than 9% is considered poor and indicate a need for lighting adjustment, higher magnification or a CCTV. A contrast threshold of higher than 25% can be considered very

poor and a CCTV or non-visual intervention is needed for fluent reading (Whittaker and Lovie-Kitchin, 1994).

Studies (Rubin and Legge1989, Whittaker and Lovie-Kitchin 1993) found that letter contrast correlates more accurately with reading speed than grating contrast. Ginsburg (1978) reported that small characters need increased contrast for identification rather than detection. Van-Nes and Jacobs (1981) found that the accuracy of letter recognition did not decrease until the contrast was below 0.12 Michelson contrast. Crossland et al. (2005) found that the baseline contrast measurements were predictive of future reading speed for patients with AMD. Legge et al. (1987) found that reading rates were highest for letters ranging in size from 0.25 to 2 degrees at 40cm, within this range, reading was very tolerant to contrast reduction for 1 degree sized letters, reading rate decreased by less than a factor of two for a tenfold reduction in contrast.

Brown (1981) reported that higher contrast was more critical to cataract patients when compared to AMD patients, in terms of reading performance with CCTVs. The authors also found that word recognition speed in patients with visual impairment was more predicted by contrast sensitivity (measured by Arden plates) than visual acuity. In patients with visual impairment who had cloudy ocular media, there was a higher reading speed for white text on a black background compared to black text on a white background and this could be due to light scatter (Legge et al., 1985), but no effect of contrast polarity (reverse) on reading performance in normally sighted people (Legge et

al., 1985). On the other hand, Bauer and Cavonius (1980) reported more errors when subjects read white text on a black background.

Leat and Woo (1997) found that contrast measured with Pelli-Robson charts, Cambridge grating charts, Regan charts, University of Waterloo charts (UW charts), and Vistech charts was predictive of reading speed. The authors found that Cambridge grating charts and Pelli-Robson charts were the best charts to measure medium to low contrast; UW charts and Regan charts for medium to high contrast whereas the Vistech chart is useful for testing contrast at all levels (Leat and Woo, 1997).

6) Visual field:

A lower reading speed for patients with central visual field defects was found compared to normally sighted people (Legge et al. 1985, Legge et al. 1987, Lovie-Kitchin and Woo 1988, Legge et al. 1992). Ergun et al. (2003) found that the size of the absolute scotoma was significantly correlated with reading speed and reading acuity. Whittaker and Lovie-Kitchin (1993) suggested that to achieve 'fluent' reading (88 words/ minute), the central scotoma must be less than 22 degrees. The authors also reported that 'high fluent' reading (174 words/ minute) can be achieved with a central scotoma of 4 degrees. On the contrary, scotoma size was not predictive of reading performance in patients with visual impairment (Legge et al. 1992, Cummings et al. 1985, Fletcher et al. 1999, Ergun et al. 2003, Sunness et al. 2007). Nguyen et al. (2011) suggested that the pattern of eccentric viewing that patients with visual impairment develop differs according to the aetiology behind the central field scotoma.

7) Field of view:

As magnification increases to the maximum the field of view will be restricted to the minimum (Schurink et al., 2011). Den-Brinker and Bruggeman (1996) reported that the field height and width had a significant effect on reading speed. The window size was found to affect reading speed with and without navigation in patients with visual impairment (Legge et al. 1985, Fine et al. 1996, Fine and Peli 1996). Legge et al. (2001) suggested that if the visual span is reduced the reading rate will be lower. A field of view of 4 to 5 characters was found sufficient for fluent reading (88 words/ minute) (Legge et al. 1985, Whittaker and Lovie Kitchin 1993). However, Rayner et al. (1982) found that a window size of 15 characters to the right of the fixation point increased the reading speed. Also, Den-Brinker and Bruggeman (1996) reported that a large field of view was required for page navigation. In optical low vision aids, high magnification levels restrict the field of view which significantly reduced reading speed (Dickinson and Fotinakis, 2000). This might be attributed to higher magnification that was not accompanied with a proportional increase in the number of saccades (Dickinson and Fotinakis, 2000). In comparison, Lowe and Drasdo (1990) suggested that the field of view of patients with a visual impairment using CCTVs was approximately equal to the normal field of view, for manual scanning. Den-Brinker and Bruggeman (1996) found that when the window size (width and height) with CCTVs was increased the time required to read a line was decreased, and the number of the required saccades was decreased.

9) Ocular movements:

Dickinson and Fotinakis (2000) suggested that patients with visual impairment had a slow reading speed compared to normally sighted people because the limited size of the saccades. Also, Rumney and Leat (1994) found shorter saccades in patients with visual impairment (different ocular conditions) using the optimal low vision aids. Bowers and Lovie-Kitchin (2001) found that the regressive saccades were decreased using low vision aids.

10) Page navigation requirements:

Page navigation refers to the movement of the low vision aid during reading (Harland et al., 1998). This might be restricted by the low vision aids ergonomics. Page navigation was found to be more problematic with hand-held magnifiers and EVES (Beckmann and Legge, 1996), and a larger field of view was required for page navigation (Beckmann and Legge 1996, Den-Brinker and Bruggeman 1996). Reading and page navigation were affected by the window size (Fine et al., 1996). CCTVs did not affect the field of view when manual scanning was required (Lowe and Drasdo, 1990). Harland et al. (1998) compared the reading performance with four different text presentation methods (CCTVs, mouse devices, drift, and Rapid Serial Visual Presentation RSVP). With CCTVs, the text is moved on an X-Y table to be viewed by a camera mounted to a monitor. With mouse devices, the mouse within which a camera is incorporated is moved over the text. With drift, a line of text drifts/ moves from right to left across the screen. With RSVP, a computer presents words, one at a time, at the same place on the monitor. They found that RSVP and sensomotoric training (SM) presentation methods increased reading rate.

There was no difference in reading speed using CCTVs or mouse devices (both required manual navigation) in normally sighted and patients with visual impairment (Harland et la., 1998). Drift and RSVP methods had less navigational requirements which resulted in higher reading speeds (85% and 169% faster, respectively) in normally sighted people. Significant differences between different presentation methods were not found among people with central visual field loss, but drift and RSVP methods improved reading performance in patients with intact central fields (Harland et la., 1998). It was suggested that a larger field of view could be required for page navigation.

11) Reading text characteristics:

Legge et al. (1985) reported that reading rate can be affected by text characteristics such as text size and contrast. Large text size resulted in slower reading speed because of the decreased number of saccades (Bullimore and Bailey, 1995). Lovie-Kitchin et al. (2000) found that rauding (Carver, 1993) rate was associated large print size without low vision aids and large print size was more predictive of oral reading speed with low vision aids. In peripheral vision, reading speed was increased with increasing text size until the critical font size was reached; then the maximum reading rate becomes constant at larger letter sizes (Chung et al., 1998). In patients with visual impairment, reading rate was higher using Courier font compared to Times New Roman font, and the critical print size was smaller for Courier font (Mansfield et al., 1996).

12) Media clarity:

Legge et al. (1985) findings suggested that patients with visual impairment who had ocular media opacity had higher reading speed using a white letter on a black background (i.e. contrast reverse). This suggests that contrast reversal has potential to improve performance in patients with cataract. However, Legge et al. (1987) found that patients with ocular media opacities did not show a better reading speed using white letters on a black background.

13) Ocular dominance:

Zeri et al. (2011) studied the effect of ocular dominance on the visual functions, and found that ocular dominance had no effect on the visual functions including reading performance.

14) Reading rate and comprehension:

Carver (1990) found that reading rate and comprehension were positively related; Legge et al. (1989) found that slow reading rate was a predictor of poor reading comprehension. On the other hand, Watson et al. (1992) found that reading rate was not predictive of reading comprehension in adults with visual impairment who demonstrated good comprehension before becoming visually impaired.

In summary, there has been no literature that evaluated the use of, and prescribing trends for PELVAs in patients with a visual impairment. Therefore, this thesis aims to inform those who prescribe or choose PELVAs about the functions or attributes that are

most important when considering their use for people with a visual impairment. Also, we aim to evaluate PELVAs from different perspectives including their parameters and/ or features, their use, their prescribing patterns, and factors that affect reading performance with these devices. The objectives of this thesis were: to compare the reported manufacturers' magnification and screen size of PELVAs to that measured in an independent setting, to measure the luminance contrast that PELVAs could provide in different independent settings, to estimate the resolution limit of currently available PELVAs, to describe the clinicians' prescribing patterns for PELVAs for patients with a visual impairment attending the Low Vision Service Wales, to determine the characteristics of patients with a visual impairment who would benefit from PELVAs, to assess patients' self-reported satisfaction of PELVAs compared to optical devices, to evaluate what patients with a visual impairment use PELVAs and optical low vision aids for, to evaluate the usefulness of low vision aids for a group of visual tasks such as reading a newspaper, and reading price labels, to evaluate the frequency and duration of reading that can be achieved with PELVAs and optical low vision aids, to compare PELVAs and optical low vision aids from the patients' perspective in terms of purpose of use, rating their use and satisfaction, and reading frequency and duration, and to determine the factors (visual functions and/ or devices parameters) that affect reading performance of patients with a visual impairment who are using PELVAs.

CHAPTER 3: Pocket and portable electronic low vision aids: Do manufactures provide an accurate description? [Magnification and Screen Diameter]

3.1. Introduction

PELVAs are a relatively a new type of low vision aids. They are easy to operate, feature few buttons and/ or controls to operate and manipulate the devices, are small (often pocket sized) which might make them convenient to be used at different places such as in the office, school, bus, etc. They have a smart appearance which may draw less attention to people with a visual impairment when they use them compared to optical magnifiers.

The image for a viewed text or an object is displayed on a small display screen. These devices provide a magnified image for which there are different zoom levels available. The image can also be viewed with different contrast settings/ modes. PELVAs have features such as a variable contrast control. This allows the users to vary the way in which the image is displayed. For example, if viewing black writing on a white background the users can view the image where the image contrast relationship is the same as the target; in this example a black target on a white background (Figure 3.1, Left). Alternatively, they could choose contrast reverse (where the image contrast relationship is opposite to the target); in this example a white target against a black background (Figure 3.1, Right). There are also options for various colour combinations e.g. yellow target against blue background. PELVAs enable a refreshed image and a snapshot view, by which the image can be frozen temporarily. The brightness of some

PELVAs can be manipulated via an on/ off brightness button. The power is provided by chargeable batteries. Common features of PELVAs are shown in Figures 3.1 and 3.2.

Figure 3.1: A PELVA (Compact+) is used by people with visual impairment to magnify a text or an object and to enhance contrast. The image contrast relationship is the same as the target; in the example a black target on a white background (Left). The image contrast relationship is opposite to the target (contrast reverse); in this example a white target against a white background (Right).

Figure 3.2: A PELVA (Compact+) incorporates: 1) a display screen, 2) a collapsible handgrip, 3) an on/off switch, 4) a snapshot button to freeze an image on the display screen temporarily, 5) a power adaptor for rechargeable batteries, 6) a camera unit: auto-focus camera, 7) a battery compartment, 8) a mode button for a contrast viewing mode selection (e.g. a black letter on a white background or a white letter on a black background), and 9) a magnification dial: a control to change magnification levels.

From Chapter 2, it is clear that very few studies have evaluated the effectiveness of low vision aids in assisting people with a visual impairment to perform daily life tasks (Bullimore and Bailey 1989, Whittaker and Lovie-Kitchin 1993, Bailey et al. 1994, Lighthouse National Survey on Vision Loss 1995 , Goodrich and Kirby 2001, Wolffsohn and Peterson 2003, Peterson et al. 2003, Culham et al. 2004, Crossland and Silver 2005, Jutai et al. 2005, Culham et al. 2009, Virgili and Acosta 2009, Nguyen et al. 2009). None have evaluated the effectiveness of PELVAs for people with a visual impairment, however the Wales Council for the Blind evaluated children's response regarding the use of 11 pocket electronic magnifiers for school activities in focus groups (Dyment,

2009). They reported children comments and concerns about the use of these magnifiers in order to recommend the most effective electronic magnifier for school-age children (Dyment, 2009).

An important part of studying the effectiveness of a particular management option for people with a visual impairment is to investigate the properties of the devices prescribed, and thereafter to examine if the patients requirements can be met by the chosen device. This is important in order to help patients and clinicians to choose the most appropriate device, and to save time, effort and money by avoiding too much 'trial and error' in reaching a decision. Bullimore and Bailey (1989) reported that manufacturers do not necessarily provide accurate information about the optical parameters of stand magnifiers. Also, Bailey et al. (1994) reported that information provided by manufacturers about optical low vision magnifiers may not be sufficient to estimate the resolution improvement that they actually provide. Clinicians have to determine the key parameters of devices used in their practice, as they might be misreported or not reported at all by manufacturers. Bailey et al. (1994) recommended that ''until manufacturers provide the required technical information about their devices, clinicians must determine these parameters for themselves or obtain the information from other sources''.

In their study, Bailey et al. (1994) measured the image distance, the equivalent power of the lens system, and the enlargement ratio for optical magnifiers (92 stand magnifiers and 53 hand-held magnifiers). They used three different eye-to-lens distances for each

magnifier (i.e. at 2.5, 10 and 25cm). The equivalent viewing distance (EVD), the eye to image distance and the predicted width of field were calculated. The authors explained that EVD is important in predicting the resolution performance. For an individual patient, the resolution limit will be directly proportional to the EVD. The eye-to-image distance is useful to indicate if the patient will have appropriate focus or whether the reading addition has to be adjusted (Bailey et al., 1994). The EVD for hand-held magnifiers is equal to the equivalent focal length, if the lens is used to form the image at or close to infinity. Accommodation demand in a given situation is determined by the sum of the image-to-lens distance and the lens-to- eye distance (Bailey et al., 1994).

The EVD is the distance at which the object would subtend an angle that is equal to the angle that the image subtends at the patient's eye. In stand magnifiers, EVD = eye-to-image distance/ enlargement ratio (Bailey et al., 1994). Bailey et al. (1994) found that the threshold print size will be directly proportional to EVD (e.g. if the EVD is halved, the size of the smallest resolvable print is also halved). They reported that for 'any viewing system with known EVD' the resolution limit can be predicted by the equation **Resolution unit (M units) = EVD for initial resolution/ initial viewing distance** (Bailey et al., 1994). They defined the field size as the lens size multiplied by the equivalent power (Fe) and divided by the eye-to-lens distance and all of these variables are available in tables for optical magnifiers (Bailey et al., 1994), examples of stand magnifiers optical parameters are shown in Table 3.1.

Manufacturer ID No.	Description	Illum Adjust. Code	Lens Size (mm)	Measured			Predict Performance (Z= Eye/ Lens distance cm)									EVD-EVP
				Fe D	I Cm	ER X	Z= 2.5			Z= 10			Z= 25			
							EVD	Ey/Im	Fld	EVD	Ey/Im	Fld	EVD	Ey/Im	Fld	
Peak 8-16X	8X-16X zoom	Zoom	10	68.7	##	##	1.5	##	6	1.5	##	1	1.5	##	1	1.25-80
Mattingly 22X Ill a	22X Illum	be ih	17	66.4	##	##	1.5	##	10	1.5	##	3	1.5	##	1	
Peak #1996 L	30X Illum	b i	8	120.4	10.0	13.0	1.0	12.5	3	1.5	20.0	1	2.7	35.0	1	
Mattingly 22X Ill b	22X Illum	be ih	17	66.4	21.3	15.1	1.6	23.8	11	2.1	31.3	4	3.1	46.3	2	2.0-50

Table 3.1: Examples of stand magnifiers optical parameters. Fe = equivalent power in dioptres (D), I = image location, ER = enlargement ratio. EVD's and eye to image distance (Ey/Im) are calculated for eye-lens distances (z) of 2.5, 10, and 25 cm (EVD = Eye-to-image dist/ER). Each double-ruled divider represents one line of visual acuity assuming size progression ratio = 5/4. Equivalent Viewing Power (EVP) and Equivalent Viewing Distance (EVD) conversion benchmarks are shown on the right at each horizontal divider. Field sizes (Fld) in millimetres are based on thin lens and small pupil assumptions. Field may be limited further by aberrations or base of stand. Illumination codes: b = battery, r = rechargeable, e = electrical, I = incandescent, h = halogen (or xenon), f = fluorescent, ## = no data available (Bailey et al., 1994).

To date, no studies have investigated agreement between the manufacturers' PELVA parameters and those found in an independent setting. The aim of this study is to answer a question "Do manufacturers provide accurate and clear descriptions of pocket and portable electronic low vision aids?". This will be assessed by comparing the reported manufacturers' description of these devices with independent measurements.

There were four parts to this study:

1) The first part involved a comparison of actual PELVAs display screen size with the manufacturers quoted size.
2) The second part compared the magnification levels acquired with the PELVAs to the manufacturers quoted levels.
3) The third part involved measurements of luminance contrast of the image that PELVAs could provide for a high and low contrast letter acuity card under different levels of illumination, different viewing conditions, and black-on-white and white-on-black contrast viewing modes.
4) The fourth part describes estimates of the resolution limits that these devices may provide by employing an ISO 12233 chart as a viewing target.

This chapter describes the first and second parts; the third and fourth will be covered in Chapter 4.

3.2. Methods

3.2.1. PELVAs

Almost all suppliers and manufacturers of low vision aids in the UK were contacted; requesting the loan of currently available PELVAs.

Initially 12 PELVAs were received from suppliers which were included in this study and another 2 PELVAs were added later for the magnification repeated measurements. Devices were given symbols from A to N and symbols will be used to represent devices throughout the text.

3.2.2. Laboratory preparation and setup

A ruler with an inch scale was used to measure the display screen diameter of PELVAs. It was not possible to use a more accurate method of measurement, such as a travelling microscope with Vernier scale due to difficulty in applying the procedure when measuring devices, because the extent of movement that was required to measure the diagonal diameter was outside of the scope of the travelling microscope.

A viewing object (a single letter sized N8) from a Bailey-Lovie near acuity chart was used for measuring magnification.

Two travelling microscopes (MA and MB) (Figure 3.3) were used to measure the image sizes available from each PELVA and hence the linear or transverse magnification was calculated.

A travelling microscope is an instrument for measuring length with 0.01mm resolution. The travelling microscopes incorporated: 1) a rigid base, 2) two rails, 3) a knob for coarse adjustment, 4) screws for fine adjustment, 5) a 10X eyepiece fitted with fine cross-hairs to fix a precise position which is then read off the Vernier scale, 6) measuring scales, and 7) objectives. Microscope MA was made by PTI (England), and Microscope MB by Griffin and George (England). Both travelling microscopes have a resolution of 0.01mm. Microscope MA can travel up to 16.5 cm horizontally and up to 14 cm vertically. Microscope MB can travel horizontally up to 22 cm and vertically up to 15 cm.

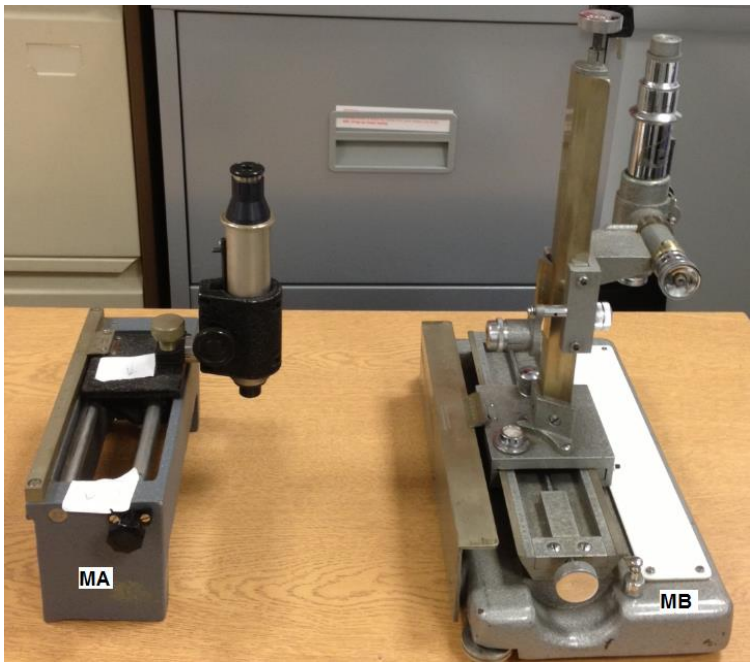


Figure 3.3: The travelling microscopes (MA and MB) used to measure image sizes. Left, Microscope (MA) by PTI (England), and right, Microscope (MB) by Griffin and George (England).

3.2.3. Measuring the display screen size

The display screen diameter was measured for 12 PELVAs (A, B, D, F, G, H, I, J, K, L, M, and N), PELVAs C and E were added at a later stage for magnification repeated measures.

The visible screen diameter (Figure 3.4) was measured in inches (because this is what most manufacturers provided) for each PELVA, by one observer, using a ruler. Measurements were repeated three times and the average was calculated.

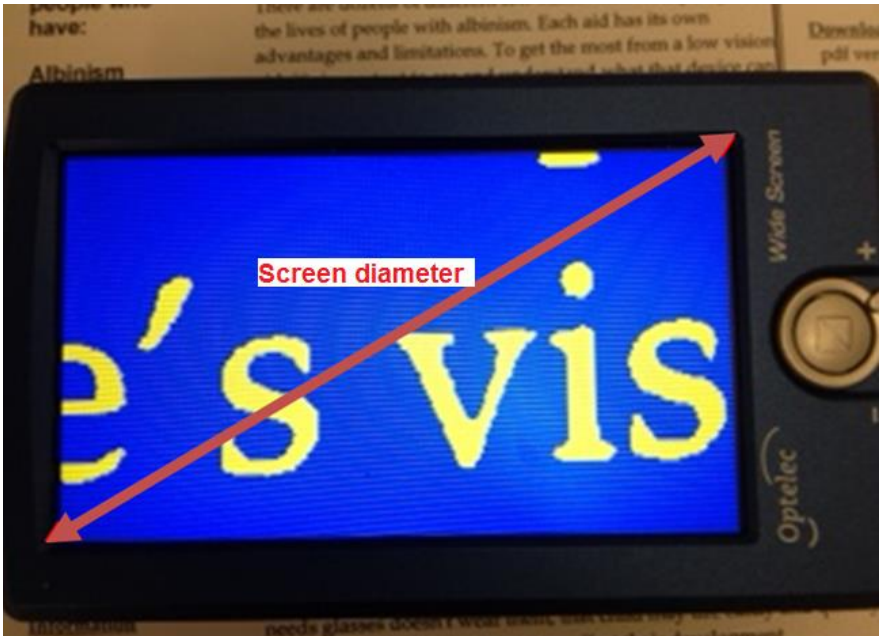


Figure 3.4: The visible screen diameter, i.e. the distance from the corner of the display screen to the opposite corner, was measured by using an inch ruler. The PELVA shown in this figure is Compact+.

3.2.4. Measuring magnification

A letter "L" sized N8 (newsprint size) (Figure 3.5) was used as a target from a Bailey-Lovie near acuity chart. The letter height (i.e. letter size) was measured three times using the travelling microscope (MA) with Vernier scale and found to be 1.90 mm, standard deviation (SD) < 0.004.

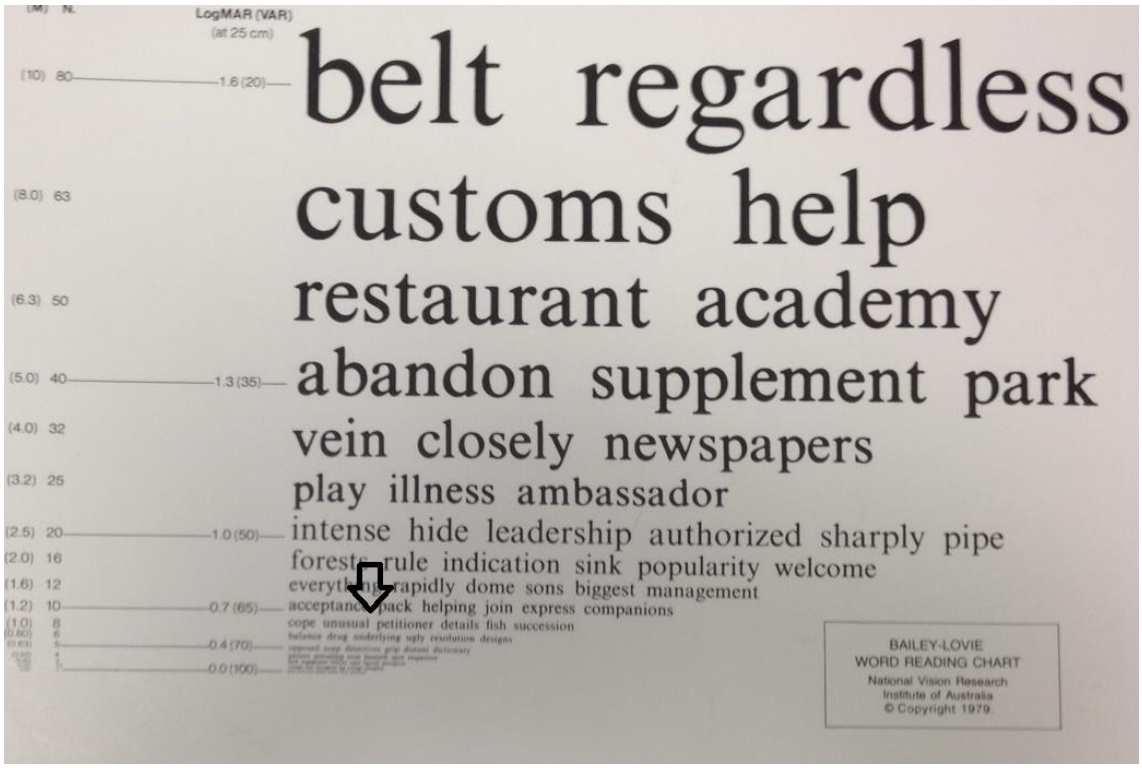


Figure 3.5: Small "L" letter sized N8 on a Bailey-Lovie near acuity chart was used as a viewing object in order to measure the image size. The image is minified (50% of the actual size).

The image of the N8 sized letter was taken under the static viewing mode (i.e. a snapshot was taken using the freeze button). The distance between the device and the viewed letter for each PELVA was set according to manufacturers' instructions in terms of

viewing distance/ angle (some PELVAs require a particular viewing angle and these were supplied with a stand).

The letter image height on each PELVA, under different magnification levels, was measured at each zoom level (zoom levels were different for different PELVAs); each measurement was repeated three times in order to ensure repeatability of measurements.

The average image size for each magnification level was calculated and divided by the letter size to get the transverse magnification (Transverse magnification = Image size / Object size), i.e. enlargement ratio (Dickinson and Fotinakis, 2000).

i. Agreement of magnification measurements made using different microscopes

Measurements of the magnification levels provided by 4 PELVAs (B, C, D, and E) were made by 2 observers, using two microscopes (MA and MB). Each observer made 3 measures for each magnification level, using each microscopes. A 3rd observer could not finish the measurements using microscope MA, but did finish the measurements with microscope MB. Therefore, we had measurements from two observers for both microscopes and three observers for microscope MB.

ii. Agreement of magnification measurements made by different observers

Measurements of the magnification provided by 4 PELVA (B, C, D, and E) were made by 3 observers (observer 1 i.e. the author, observer 2, and observer 3) using microscope MB. Each observer made 3 measures for each magnification level. Agreement between the three observers was assessed using only one microscope (MB).

Agreement between the travelling microscopes MA and MB, and between three observers (1, 2, and 3) was assessed using Bland-Altman plots. Bland-Altman plots assess agreement and were more useful in this context than the use of correlation coefficients. Correlation between two sets of measurements can be high but agreement may be poor (Chan 2003, McAlinden et al. 2011).

3.3. Results

3.3.1. Display screen size

The difference between measured and reported diameter for 12 PELVAs is shown in Table 3.2 and Figure 3.6. Reported manufacturer diameter for the 12 PELVAs (A, B, D, F, G, H, I, J, K, L, M, and N) ranged from 2.80 to 6.50 inches, their measured diameter [mean of three measurements by 1 observer] ranged from 2.81 inches to 6.39 inches (the mean difference between measured and reported screen diameter was -0.03 ±0.07 inch). The percentage difference between measured and reported diameter ranged between 0.00 and 4.29%. Although differences between measured and reported diameter were small, they were statistically significant (One sample t-test, $p < 0.05$) for all PELVAs except PELVAs (B and I).

According to the measured screen diameter, devices were divided into two sub-groups of PELVAs. The first can be described as small pocket size PELVAs; these include PELVAs with screen diameter of 3.5 inches or less (i.e. F, G, J, K, and L). The second can be referred to as larger PELVAs, these include PELVAs with screen size of greater than 3.5 inches (i.e. A, B, D, H, I, M, and N). These criteria are not used by manufacturers. The criterion of 3.5 inches or less for the PELVA was decided, because a PELVA with a diameter of 3.5 inches can be fitted in a pocket. This grouping might also be important for clinicians to consider when a larger field of view is required possibly for a higher reading speed.

PELVA	Reported screen diameter (inches)	Measured screen diameter using an inch-ruler (Mean of three measurements ± SD) (inches)	Difference[1] (inches)	Ratio (%)[2]	Percentage difference[3]
A	6.50	6.39±0.008	-0.11**	98.31%	1.69%
B	4.30	4.30±0.001	0.00	100.00%	0.00%
D	5.00	4.99±0.046	-0.01**	99.80%	0.20%
F*	3.50	3.38±0.006	-0.12**	96.57%	3.43%
G*	3.50	3.35±0.002	-0.15**	95.71%	4.29%
H	4.30	4.24±0.005	-0.06**	98.60%	1.40%
I	4.30	4.30±0.001	0.00	100.00%	0.00%
J*	3.00	3.02±0.002	0.02**	100.67%	0.67%
K*	3.50	3.51±0.004	0.01**	100.29%	0.29%
L*	2.80	2.81±0.004	0.01**	100.36%	0.36%
M	4.30	4.34±0.008	0.04**	100.93%	0.93%
N	4.30	4.36±0.008	0.06**	101.40%	0.40%

[1] Difference = Mean measured diameter – Reported diameter
[2] Ratio (%) = Mean measured screen diameter / reported screen diameter *100%
[3] Percentage difference = (Mean measured screen diameter – Reported diameter)/ Reported diameter *100%
is the difference between measured and reported diameter to the
* small pocket size PELVAs i.e. reported screen diameter = < 3.50 inches
** Significant difference between the mean measured and the reported screen diameter ($p < 0.05$).

Table 3.2: The reported and measured screen diameter (the mean of 3 measurements) of 12 PELVAs.

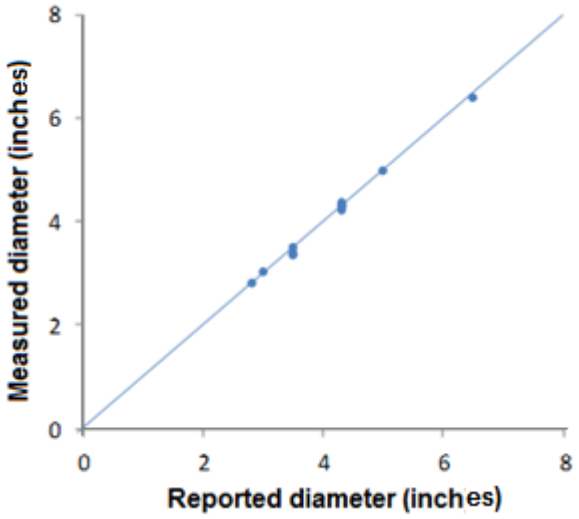


Figure 3.6: The measured screen diameter (the mean of 3 measurements in inches) and reported screen diameter of 12 PELVA. All values lie close to the reference (no change) line. Pearson Correlation Coefficient = 0.998 ($p < 0.001$).

3.3.2. Magnification

3.3.2.1. Inter-microscope differences (a comparison of two travelling microscopes (MA and MB))

There was no significant difference in measured magnification using both travelling microscopes (MA and MB) by 2 observers (3 measurements by each observer with each microscope i.e. 6 measurements) for 4 PELVAs (B, C, D, and E).

Data (measurements using both microscopes, by two observers) were normally distributed (Shapiro Wilk test, $p > 0.05$). The mean difference in measured magnification between the microscope MA and the microscope MB was 0.035 ±0.25 (Paired sample t-test, $p > 0.05$). Measured magnification using the travelling microscopes MA and MB is shown in Table 3.3.

	PELVA	Manufacturer's zoom level	MA Mean±SD	MB Mean±SD
Observer 1	B	5.00	5.77 ±0.00	5.98±0.08
		7.50	8.62±0.04	8.39±0.10
		10.00	11.87±0.02	11.68±0.04
	C	1.70	1.38±0.04	1.54±0.10
		12.00	13.01±0.11	13.07±0.05
	D	1.50	1.59±0.02	1.73±0.01
		18.00	19.06±0.03	18.87±0.01
	E	2.00	2.76±0.06	2.64±0.09
		24.00	21.77±0.20	22.15±0.14
Observer 2	B	5.00	5.80±0.01	6.29±0.14
		7.50	8.66±0.07	8.21±0.03
		10.00	11.79±0.04	11.62±0.07
	C	1.70	1.50±0.01	1.57±0.05
		12.00	12.90±0.03	12.86±0.12
	D	1.50	1.54±0.04	1.69±0.02
		18.00	18.48±0.07	18.67±0.21
	E	2.00	2.63±0.05	2.71±0.03
		24.00	22.21±0.18	22.35±0.21

Table 3.3: Measured magnification using the travelling microscopes MA and MB (two observers (1 and 2), 3 measurements each at each zoom level).

Bland-Altman plot showed that limits of agreement [Mean + 2*SD and Mean – 2*SD] were 0.54 and -0.47, measurements were distributed equally above and below the mean difference line, 95% confidence intervals [Limits of agreement ± Corresponding value of Degree of Freedom DF on t-tables * Standard Error SE] were 0.61 and 0.47 for the upper limit, and -0.40 and -0.54 for the lower limit (Figure 3.7).

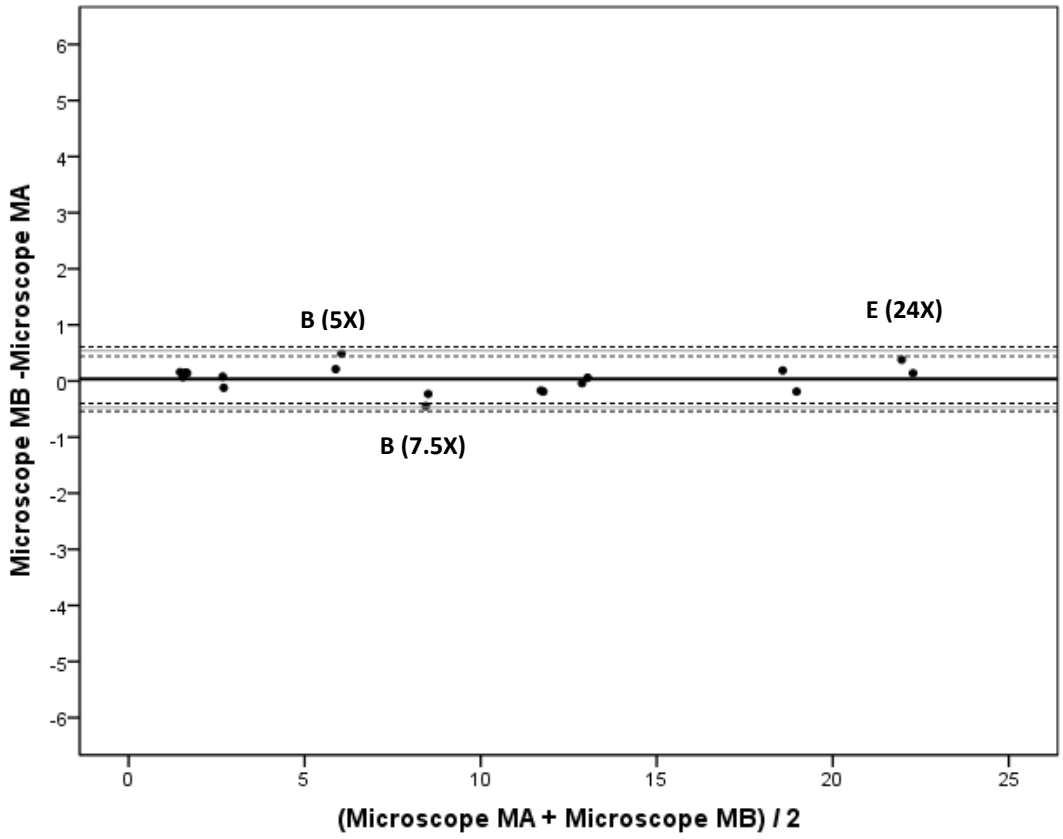


Figure 3.7: Bland-Altman plot shows the differences in magnification measurements between Microscope MA and Microscope MB. Magnification was measured for 4 PELVAs (B, C, D and E) by 2 observers (3 measurements each (n=6), at each zoom level). Mean difference (0.035) (bold black line); limits of agreement 0.54 and -0.47 (grey lines); 95% confidence intervals 0.61 and 0.47 for the upper limit, and -0.40 and -0.54 for the lower limit (dashed lines). Poorest agreement was for PELVA B (5X and 7.5X), and PELVA E (24X).

3.3.2.2. Inter-observer differences (a comparison of 3 observers)

The magnification measurements made by each of the three observers were normally distributed (Shapiro Wilk test, $p > 0.05$). There was no significant difference in measured magnification by 3 observers (1, 2, and 3) using microscope MB i.e. 3 measurements by each observer at each zoom level for 4 PELVAs (B, C, D, and E) (ANOVA: $F = 0.42$, F critical $= 3.11$, $p > 0.05$). Measured magnification by three observers is shown in Table 3.4.

PELVA	Manufacturer's zoom	Observer 1 (Mean ± SD)	Observer 2 (Mean ± SD)	Observer 3 (Mean ± SD)	Observer 1 vs. Observer 2		Observer 1 vs. Observer 3		Observer 2 vs. Observer 3	
					Deviation from ISO 15253:2000 standard	Fall within ISO15253:2000 standard?	Deviation from ISO 15253:2000 standard	Fall within ISO15253:2000 standard?	Deviation from ISO 15253:2000 standard	Fall within ISO15253:2000 standard?
B	5	5.98±0.08	6.29±0.14	5.46±0.36	5%	✓	-9%	X	-13%	X
	7.5	8.39±0.10	8.21±0.03	††	-2%	✓	††	-	††	-
	10	11.68±0.04	11.62±0.07	12.61±0.50	-1%	✓	8%	X	9%	X
C	1.7	1.54±0.10	1.57±0.05	2.14±0.02	2%	✓	39%	X	36%	X
	12	13.07±0.05	12.86±0.12	9.14±0.07	-2%	✓	-30%	X	-29%	X
D	1.5	1.73±0.01	1.69±0.02	2.23±0.06	-2%	✓	29%	X	32%	X
	18	18.87±0.01	18.67±0.21	19.22±0.05	-1%	✓	2%	✓	1%	✓
E	2	2.64±0.09	2.71±0.03	2.68±0.10	3%	✓	2%	✓	-1%	✓
	24	22.15±0.14	22.35±0.21	18.70±0.22	1%	✓	-16%	X	-16%	X

Table 3.4: Measured magnification of 4 PELVAs (B, C, D, and E) by 3 observers (1, 2, and 3) using the travelling microscope MB. The mean and standard deviation of three measurements by each observer at each zoom level. (††) Magnification was not measured at this zoom level by observer 3 (i.e. missing data therefore data in the whole highlighted row were removed from inter-observers analysis). The ISO15253:2000 (BSI, 2000) for magnification tolerance: for equivalent power of =< 12 the tolerance is 5%, for equivalent power of > 12 and =< to 20 the tolerance is 10%, and if the equivalent power is > 20 the tolerance is 15%. ✔ PELVA's magnification was within the ISO15253:2000 standard (BSI, 2000). X PELVA's magnification deviated significantly from the ISO standard.

There was no significant difference between magnification measured by observer 1 and observer 2. The mean difference in measured magnification between observer 1 and 2 was -0.004 ± 0.22 (ANOVA: F = 1.72E-05, F critical = 4.03, $p > 0.05$), Pearson Correlation Coefficient = 0.97 ($p < 0.001$). Bland-Altman plot showed that limits of agreement were 0.43 and -0.43; 95% confidence intervals were 0.34 and 0.52 for the upper limit, and -0.52 and -0.34 for the lower limit (Figure 3.8). All differences between observer 1 and observer 2 measurements lie within the ISO15253:2000 standard (BSI, 2000) (Table 3.4).

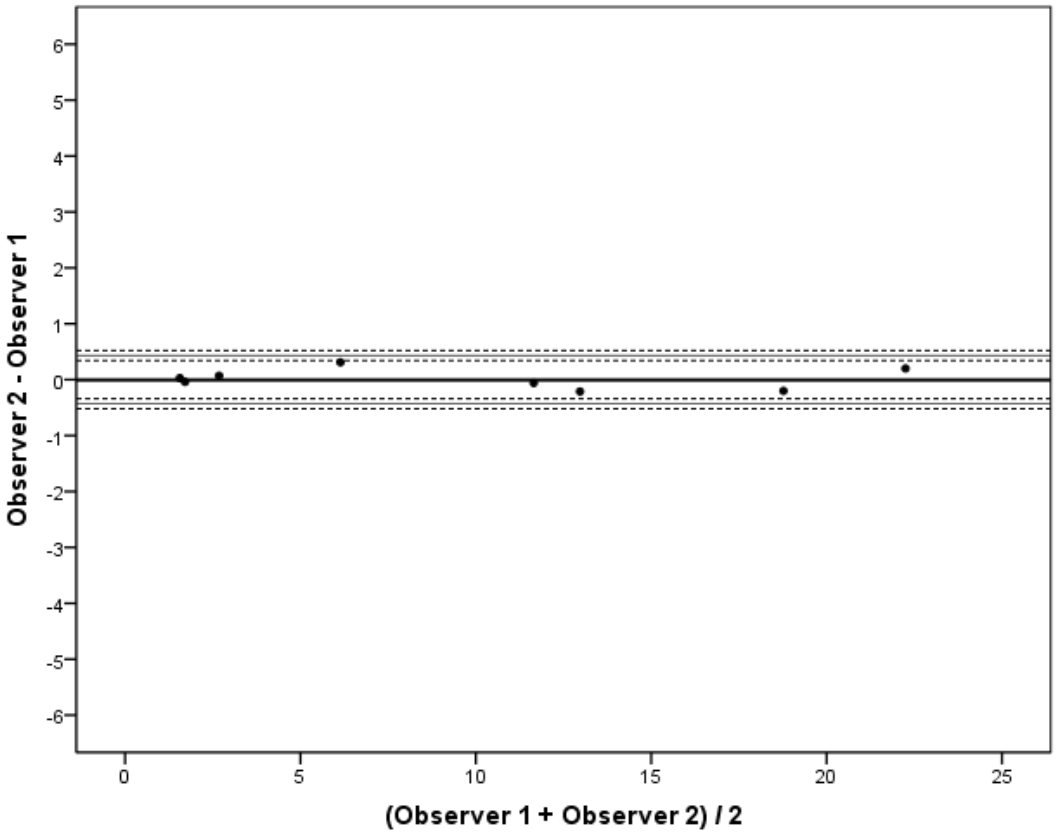


Figure 3.8: Bland-Altman plot shows the differences in magnification measurements between observers 1 and 2 using microscope MB. Mean difference -0.004 (black bold line), limits of agreement 0.43 and -0.43 (grey lines), 95% confidence intervals 0.34 and 0.52 (dashed lines) for the upper limit, and -0.52 and -0.34 (dashed lines) for the lower limit.

There was no significant difference between magnification measured by observer 1 and observer 3. The mean difference in measured magnification, of PELVAs B, C, D and E, between observer 1 and 3 was -0.57 ± 1.90 (ANOVA: F = 0.63, F critical = 4.03, $p > 0.05$), Pearson Correlation Coefficient = 0.90 ($p < 0.001$). Bland-Altman plot showed limits of agreement were 3.23 and -4.37, and 95% confidence intervals were 2.43 and 4.03 for the upper limit and -5.17 and -3.57 for the lower limit (Figure 3.9). However, two out of 8 differences between observer 1 and observer 3 measurements lie within the ISO15253:2000 standard (BSI, 2000), and 6 differences lie outside the standard (Table 3.4).

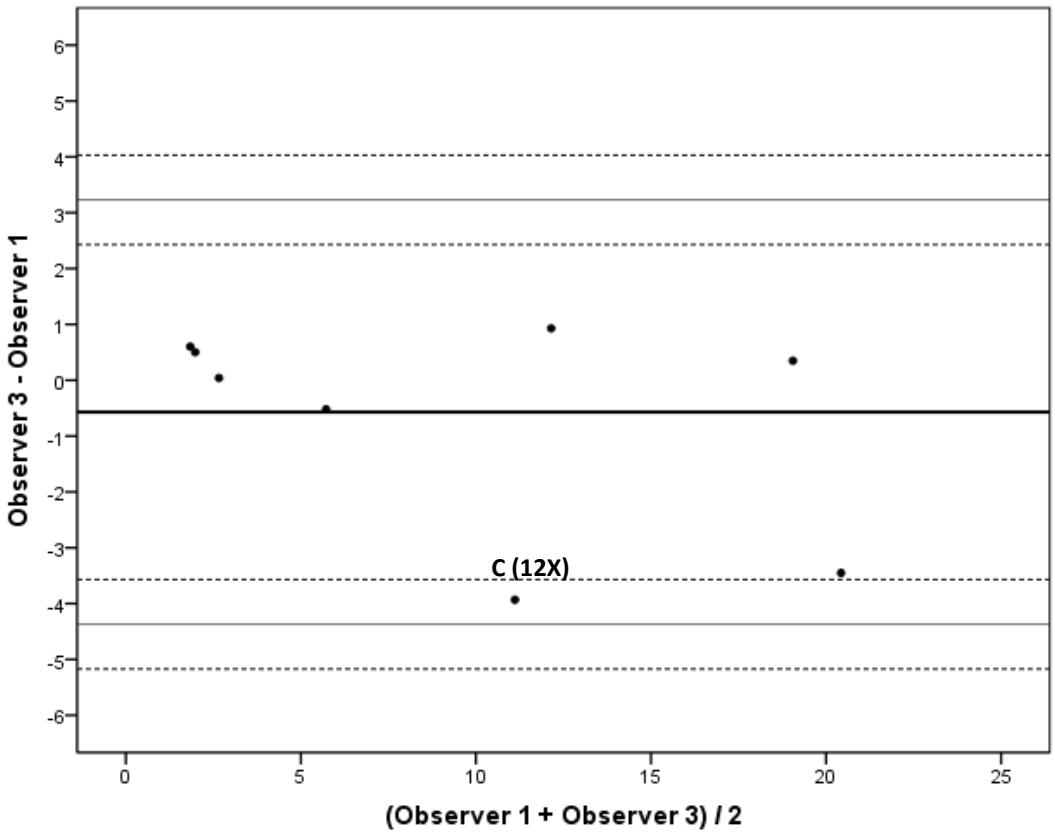


Figure 3.9: Bland-Altman plot shows the differences in magnification measurements between observers 1 and 3 using microscope MB. Mean difference -0.57 (bold black line), limits of agreement 3.23 and -4.37 (grey lines), 95% confidence intervals 2.43 and 4.03 (dashed lines) for the upper limit, and -5.17 and -3.57 (dashed lines) for the lower limit. The poorest agreement was for PELVA C (12X).

There was no significant difference between magnification measured by observer 2 and observer 3. The mean difference in measured magnification between observer 2 and 3 was -0.57 ± 1.91 (ANOVA: F = 0.63, F critical = 4.03, $p > 0.05$), Pearson Correlation Coefficient= 0.90 ($p < 0.001$). Bland-Altman plot showed that limits of agreement were 3.25 and -4.39; 95% confidence intervals were 4.30 and 2.50 for the upper limit, and –5.17 and -3.57 for the lower limit (Figure 3.10). However, two out of eight differences between observer 2 and observer 3 measurements lie within the ISO15253:2000 standard (BSI, 2000) (Table 3.4).

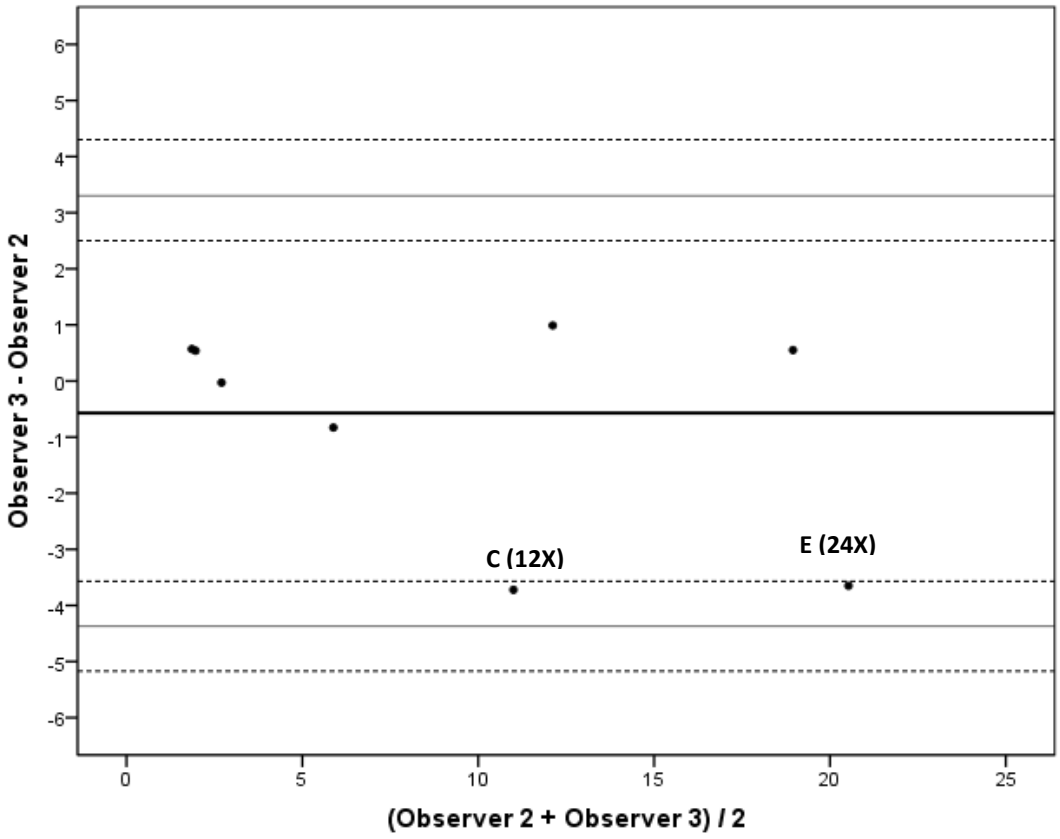


Figure 3.10: Bland-Altman plot shows the differences in magnification measurements between observers 2 and 3 using microscope MB. Mean difference -0.57 (bold black line), limits of agreement 3.25 and -4.39 (grey lines), 95% confidence intervals 4.30 and 2.50 (dashed lines) for the upper limit, and –3.57 and -5.17 (dashed lines) for the lower limit. The poorest agreement was for PELVA C (12X), and PELVA E (24X).

3.3.2.3. Manufacturer versus measured magnification

Manufacturer magnification compared to measured magnification

As the inter-observer and inter-microscope differences for magnification measurements were not significantly different as shown in Sections 3.3.2.1 and 3.3.2.2, transverse magnification was measured for 14 PELVAs (A-N) by 1 observer (1) using 1 microscope (MA) and was compared to the manufacturer reported magnification. One PELVA (N) was removed because it had a technical fault.

Data were normally distributed (Shapiro Wilk test, $p > 0.05$). The reported manufacturers' magnification for 13 PELVAs (A to M) ranged from 1 to 42, while the measured magnification ranged from 0.57 to 27.43. The mean difference between the reported magnification and the measured magnification by observer 1 (3 measurements at each zoom level) using microscope MA for 13 PELVAs was -0.70 SD± 4.90 (Paired sample t-test, $p < 0.05$). The majority of PELVAs lie outside the ISO15253:2000 standard (BSI, 2000) for tolerance of optical magnifiers. All PELVAs except PELVA A lie outside the ISO15253:2000 for magnification tolerance, i.e. only one PELVA (A) meets the tolerance expected for all zoom levels. PELVAs D, E, and L do have one zoom level that lies within tolerance, but not all zoom levels within tolerance. Table 3.5 and Figure 3.11 show manufacturers reported magnification compared to measured magnification of PELVAs.

PELVA	Reported Magnification	Measured magnification[1] ±SD	P-Value[3]	Ratio (%)[2]	Deviation from ISO 15253:2000 standard	Fall within ISO15253: 2000 standard? ✓ or X
A	3.5	3.71±0.04	0.028*	104%	4%	✓
	14	14.46±0.06	0.004*	103%	3%	✓
B	5	5.77±0.001	0.002*	115%	15%	X
	7.5	8.62±0.03	<0.001*	115%	15%	X
	10	11.87±0.02	<0.001*	119%	19%	X
C	1.7	1.38±0.03	<0.001*	81%	19%	X
	12	13.01±0.02	0.005*	108%	8%	X
D	1.5	1.59±0.01	0.009*	106%	6%	X
	18	19.06±0.02	0.009*	106%	6%	✓
E	2	2.76±0.05	0.003*	138%	38%	X
	24	21.77±0.16	0.002*	91%	9%	✓
F	2	2.99±0.03	<0.001*	149%	49%	X
	11	24.06±0.03 †	<0.001	219%	119%	X
G	2	2.73±0.02	<0.001*	136%	36%	X
	14	5.36±0.02 †	<0.001*	38%	62%	X
H	2	4.75±0.02 †	0.002*	237%	137%	X
	7	6.59±0.02	<0.001*	94%	6%	X
	14	9.81±0.03	<0.001*	70%	30%	X
I	42	27.43±0.03 †	<0.001*	65%	35%	X
J	4	3.19±0.02	<0.001*	80%	20%	X
	6	4.56±0.04	<0.001*	76%	24%	X
	8	5.98±0.03	<0.001*	75%	25%	X
	11	7.7±0.03	<0.001*	70%	30%	X
K	1	0.57±0 †	<0.001*	57%	43%	X
	20	5.5±0.03 †	<0.001*	28%	72%	X
L	3	2.86±0.02	0.015*	95%	5%	✓
	5	4.14±0.15	<0.001*	83%	17%	X
	7	5.88±0.03	<0.001*	84%	16%	X
M	2	4.45±0.09 †	0.001*	221%	121%	X
	10	10.86±0.03	<0.001*	109%	9%	X
N††	5	4.9±0.02	0.041*	98%	2%	✓
	7.5	6.61±0.02	0.003*	88%	12%	X

Table 3.5: The reported manufacturer's magnification and the measured magnification[1] (mean of 3 measurements by observer (1) using microscope MA) for 13 PELVAs using N8 size letter. [2] Ratio= Measured magnification/ Manufacturer magnification*100%. [3] P-value was calculated for the difference between reported and measured magnification at each zoom level separately using paired-sample t-test (paired sample t-test was performed for each zoom level). * P-value was significant (p < 0.05). ISO15253:2000 (BSI, 2000) for magnification tolerance: For equivalent power of =< 12 the tolerance is 5%, for equivalent power of > 12 and =< to 20 the tolerance is 10%, and if the equivalent power is > 20 the tolerance is 15%. ✓ PELVA magnification was within the ISO15253:2000 standard (BSI, 2000). X PELVA magnification deviated significantly from the standard. All PELVAs except PELVA A lie outside the ISO15253:2000 for magnification tolerance. PELVAs D, E, and L do have one zoom level that lies within tolerance, but not all levels within tolerance. † PELVAs F, G, H, I, K, and M were outliers in Figures 3.11. †† PELVA N was removed from magnification analysis because it had a technical fault, therefore results of 13 PELVAs (A-M) are presented.

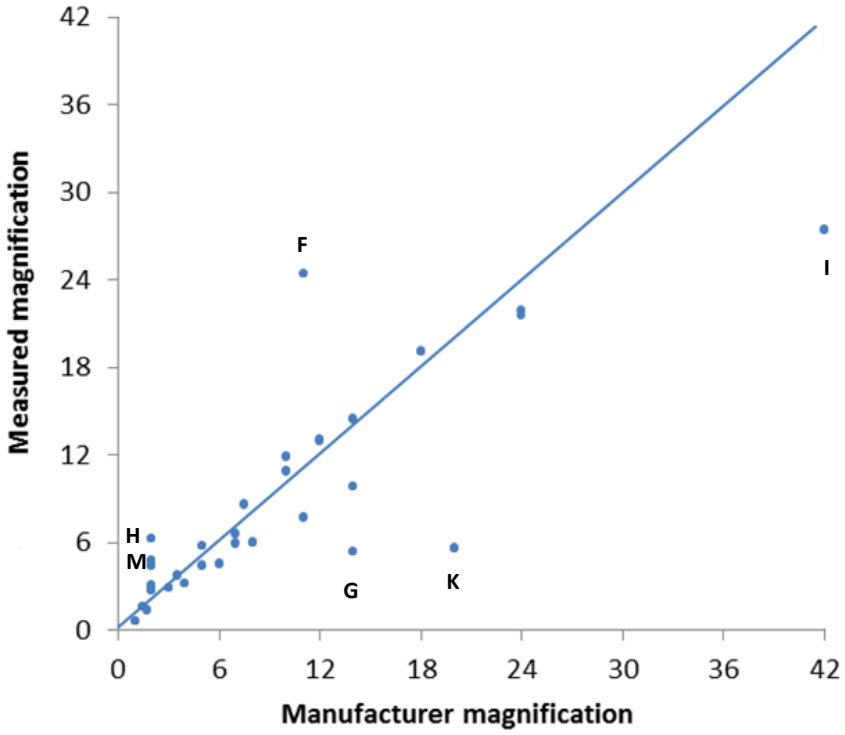


Figure 3.11: Measured magnification versus reported manufacturer's magnification for 13 PELVAs (A-M) at different zoom levels. Dots show the mean measured magnification (3 measurements at each zoom level) by observer 1 using microscope MA. Pearson Correlation Coefficient = 0.818, p < 0.001. PELVAs F, G, H, I, K, and M were outliers. All PELVAs except PELVA A lie outside the ISO15253:2000 for magnification tolerance. PELVAs D, E, and L do have one zoom level that lies within tolerance, but not all levels within tolerance, see Table 3.5.

Although, overall, correlation was high (Pearson Correlation Coefficient = 0.818, p < 0.001) (Figure 3.11), Bland-Altman plot shows that about 13% of values lie outside agreement limits (Figure 3.12). Limits of agreement were 10.50 and -9.10; 95% confidence intervals were 12.30 and 8.70 for the upper limit and -7.30 and -10.90 for the lower limit (Figure 3.12).

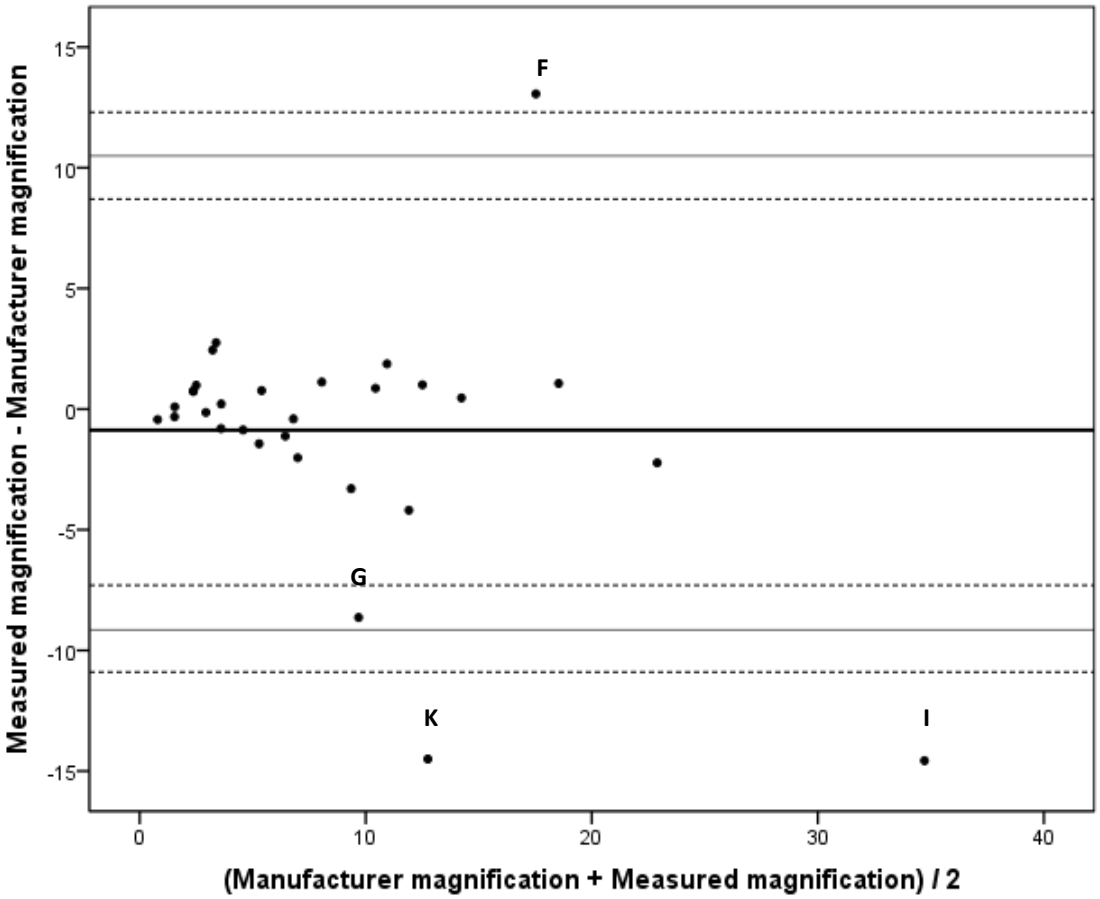


Figure 3.12: Bland-Altman plot using the absolute difference shows agreement between measured magnification (by observer 1 using microscope MA) and the reported manufacturer magnification. Mean difference -0.70 (black line) Limits of agreement 10.50 and -9.10 (grey lines), 95% Confidence intervals 12.3 and 8.7 for the upper limit and -7.3 and -10.9 for the lower limit (dashed line). Poor agreement was for PELVA G. PELVAs F, I and K were outliers.

Also, it was found that the difference between the reported and the measured magnification was greatest at higher magnification levels for some PELVAs ($p < 0.05$) (Figure 3.13).

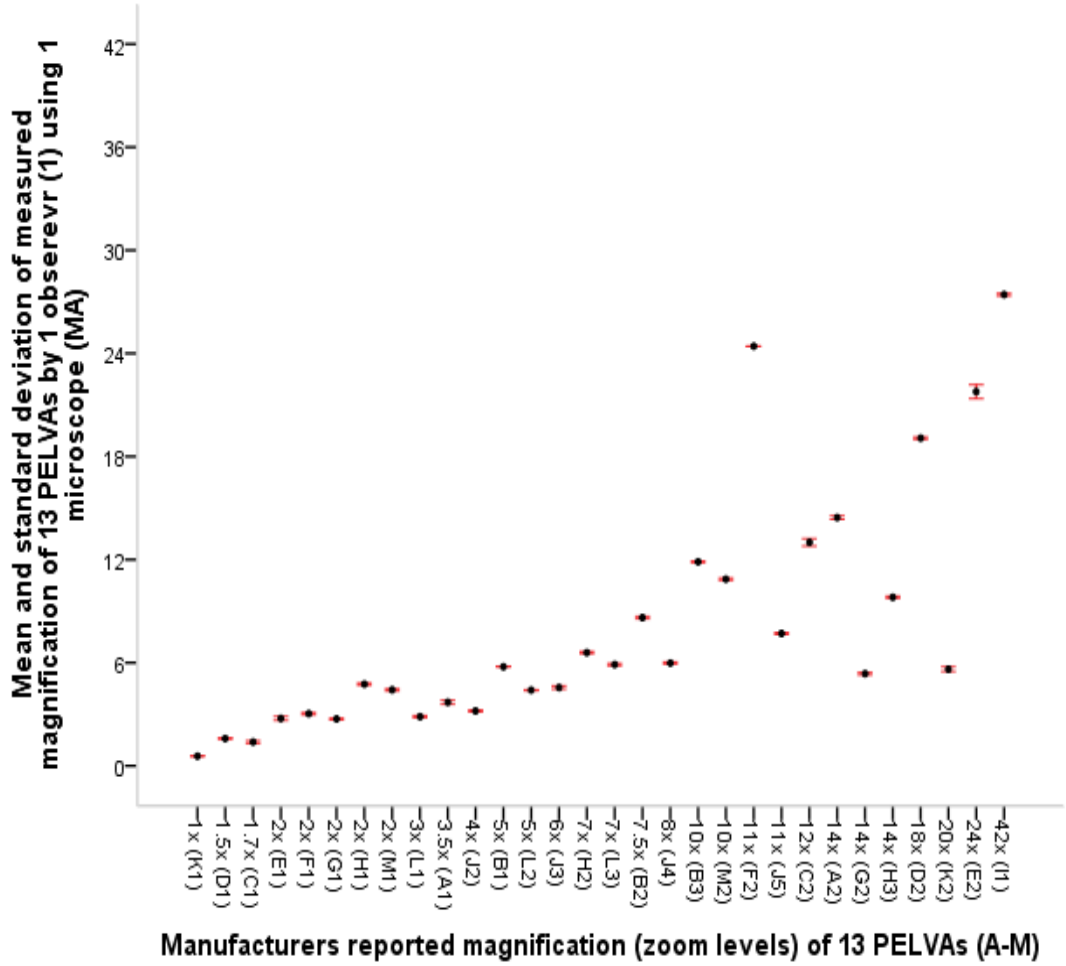


Figure 3.13: The mean and standard deviation of measured magnification of 13 PELVAs (A-M), by 1 observer (1) using 1 microscope (MA) [3 measurements at each zoom level]. Black dots show the mean of measured magnification (3 measurements) at each zoom level by 1 observers using 1 microscope. Error bars show the standard deviation of measured magnification at each zoom level. Horizontal axis show the zoom levels as reported by manufacturers for example, 7.5X (B1) = 7.5 is the value of the 1st magnification level of PELVA 'B', 12x (C2) = 12 is the value of the 2nd magnification level of PELVA 'C' as reported by manufacturers, etc.

The differences between measured magnification and manufacturers reported magnification can be expressed as percentages of the values (Method A – Method B) / Mean %) (Giavarina, 2015). Clinically, it is likely that the more useful measure would be

the difference in absolute magnification. For example, a 50% difference will be more significant at some magnifications but not others; a 50% difference of 2X magnification is 1X, but a 50% difference of 10X magnification is 5X. The 5X will be noticed by the patient, whereas the 1X may not be. Therefore, differences in absolute magnification are likely to be more important clinically.

3.4. Discussion

In this study the manufacturers reported screen diameter was compared to the measured screen diameter for 12 PELVAs. Differences between measured screen diameter and reported diameter were small (-0.03±0.07 inch). Although they were statistically significant ($p < 0.05$) for 10 PELVAs, these differences were considered unlikely to have any clinical implications.

Agreement between microscopes measurements, observers measurements, and between measured magnification and reported magnification was compared using Bland-Altman plot in which the difference between two measurements was plotted against the mean of both measurements. These showed that variations between reported manufacturers magnification and magnification measured in an independent setting were significant, and these were not attributed to inter-microscopes or inter-observers variations.

Although there was no significant difference between the mean measures for 3 observers, the limits of agreement were greater between observer 3 and the other observers compared to observer 1 versus observer 2. The difference between observer 3 and other two observers for some zoom levels were about 4 times magnification. Applying the ISO15253:2000 standard (BSI, 2000); a difference of 3.93X magnification between observers 1 and 3 for the second zoom level of PELVA C (12X) represents -30% deviation which lies outside the recommended tolerance (Table 3.4). Also, a difference of 3.65X magnification between observers 2 and 3 for the second zoom level of PELVA E

(24X) represents -16% deviation which lies slightly outside the standard. Observer 3 had presbyopia and he found it difficult to read the Vernier scale of the travelling microscope; this might contributed to the variations between observers 1 and 3, and observers 2 and 3.

Statistically, large limits of agreement could reflect a small sample (Bland and Altman, 1986), but this is less likely to be the reason because for the same sample of PELVAs the differences between observers 1 and 2 measurements were smaller.

Reported manufacturers and measured magnification were compared for 13 PELVAs. Significant variations were found between manufacturers' and reported measurements (mean difference -0.70±4.90, $p = 0.00$) which can not be explained by inter-microscope or inter-observer differences ($p > 0.05$).

The difference between measured and reported magnification was large (ranged from -14.6 to 13.1X). When the tolerances for magnification from the ISO15253:2000 (BSI, 2000) were applied to the data, the vast majority of measures fell outside these levels (Table 3.5). The ISO15253:2000 standard (BSI, 2000) to tolerance of magnifiers states that: 1) for equivalent power of less than or equal to 12 the equivalent power for magnifiers should not deviate by more than 5%, 2) the equivalent power of magnifiers of equivalent power of greater than 12 and less than or equal to 20 should not deviate by more than 10%, and 3) the equivalent power of magnifiers of equivalent power greater than 20 should not deviate by more than 15% (BSI, 2000).

Only PELVA (A) falls within the standard with deviations of 3% and 4%, for the two magnification levels (Table 3.5). Other PELVAs (B, C, F, G, H, I, J, and M) did not fall within the ISO 15253:2000 for all zoom levels and the deviation of these PELVAs was up to 137% (Table 3.5) which is large. For example, a difference between measured and reported magnification of 137% for a PELVA with 20X magnification would provide 27.4X magnification (higher than the expected) which is clinically significant. Although this study suggested that differences between reported and measured magnification were clinically significant for the majority of PELVAs (137% for some PELVAs) we preferred not to report PELVAs names.

The PELVAs have not been identified due to the limitations of the study. The limitations were that only one observer assessed the 13 PELVAs, only one sample of each type of PELVA from each manufacturer was assessed, the manufacturers methods to measure the magnification were not available, despite the fact that we approached the manufacturers regarding this matter. In order to make the study more robust it would be important to assess a random sample of each type of PELVA with an increased number of observers and measurements, and ideally repeat the measurements using the manufacturers techniques (if they can be acquired).

Therefore, it was felt inappropriate to identify each PELVA/ manufacturer; and a more robust study should be carried out before claims are made about the incorrect description of a device by manufactures. In the meantime this study highlights for clinicians that magnification levels for PELVAs may not be as expected.

3.5. Conclusion

Variations between the reported screen diameter and the measured screen diameter of PELVAs were small and were unlikely to have any clinical implication.

Variations between the reported manufacturer magnification of PELVAs and those measured independently were significant. The difference between the manufactures reported magnification and those measured varied from 3% to 137%. This could not be explained by inter-observer or inter-microscope variations. Variations between the reported manufacturer magnification and those measured were larger for high zoom levels. The magnification was outside the ISO standard for the vast majority of PELVAs and it is important that clinicians are aware of these variations to ensure that the patients' requirements are met.

PELVAs were not identified in this study because of its limitations. In future, it is important to measure magnification of different samples of each type of PELVA with more observers and using the same methods as the manufacturers (if the information can be acquired).

In order to prescribe the most appropriate electronic low vision aid, clinicians should be aware that variations may be found in magnification reported by the manufacturers and that found in independent settings.

CHAPTER 4: Luminance contrast and resolution limits of pocket and portable electronic low vision aids measured in independent settings.

4.1. Introduction

Luminance contrast and resolution are important factors affecting the quality of digital images (Peli, 1990). Many techniques have been developed to improve image contrast such as contrast manipulation and modifications including increasing the brightness of the screen (Peli, 1990).

Luminance contrast is a measure of the perceived lightness or brightness difference between object and background. For the perception of fine detail, such as in reading, contrast across edges is very important (MacIntyre and Cowan, 1994). The minimum recommended luminance contrast ratio of text and background is 3:1 (ISO9241 Part 3, 2008) and a contrast ratio of 10:1 is preferred (Ware, 2013).

Luminance contrast is usually calculated using the Michelson contrast definition or Weber contrast definition as explained below. The Michelson contrast is used to calculate the contrast of repetitive stimuli, for example gratings. It ranges between 0.00 (low contrast) to 1.00 (high contrast).

$$\textbf{Michelson Contrast} = (L_{Max} - L_{Min}) / (L_{Max} + L_{Min})$$

Where L is the luminance measured by light-meter (cd/m²), L_{Max} is the maximum luminance (i.e. luminance of the white background), L_{Min} is the minimum luminance (i.e.

luminance of the black target) (Legge et al. 1987, Legge et al. 1990, MacIntyre and Cowan 1994, Crossland et al. 2010).

Crossland et al. (2010) used the Michelson contrast to calculate the luminance contrast of Kindle and Sony electronic books. The authors did not report the method that they used to measure luminance.

MacIntyre and Cowan (1994) used the Michelson contrast definition to calculate the luminance contrast of coloured areas displayed on a Cathode Ray Tube (CRT), and proposed a method for determining the contrast of coloured areas. For this they used a contrast metric that is in wide use in visual psychophysics, and showed that the metric can be approximated reasonably without display measurement, as long as it is possible to assume that the CRT has been adjusted according to usual CRT set-up standards (MacIntyre and Cowan, 1994). By using the average adjacency relationship and the optimal 'ε' value (i.e. the contribution of a pixel to its own total luminance), a metric for measuring luminance contrast can be determined by setting L_{Max} and L_{Min} in the Michelson contrast definition to the appropriate one of L'_{dbg} and L'_{dfg} (MacIntyre and Cowan, 1994):

$$L_{Max} = \text{Max}\,(L'_{dbg}, L'_{dfg})$$

$$L_{Min} = \text{Min}\,(L'_{dbg}, L'_{dfg})$$

L'_d of the average background pixel is approximated by:

$$L'_{dbg} = \varepsilon L_{dbbg} + (1 - \varepsilon)\,(L_{dbbg} N_{bg} + Ld_{bfg}\,(1 - N_{bg}))$$

$L_{dbbg \text{ and } Ldbfg}$ are the background ($_{bg}$) and foreground ($_{fg}$) luminance contrast with black level correction (MacIntyre and Cowan, 1994). The contribution of a pixel to its own total luminance (ε) equals 0.47 (MacIntyre and Cowan, 1994). N_{bg} is the average number of background pixels adjacent to a background pixel (MacIntyre and Cowan, 1994).

L'd of the average foreground pixel is approximated by:

$$L'_{dfg} = \varepsilon L_{dbfg} + (1 - \varepsilon)\,(L_{dbbg}\,(1-N_{fg}) + L_{dbfg}N_{fg})$$

Where N_{fg} is the average number of foreground pixels adjacent to a foreground pixel (MacIntyre and Cowan, 1994).

Weber Contrast = $(L - L_b)/ L_b$

Where L is the letter luminance, L_b is the background luminance (this has to be the luminance of the immediately adjacent background to the letter) (Westheimer 1985, Peli 1990).

Weber contrast is used to calculate the contrast of a small object against a background. When the letter is darker than the background, it ranges from -1.00 (highest contrast) to 0.00 (lowest contrast); and from 0.00 to very large numbers when the background is darker than the letter.

The contrast ratio (luminance ratio) is the ratio between the highest luminance, and the lowest luminance (Contrast ratio = Highest luminance / Lowest luminance). It is often used for high luminances and for specification of the contrast of electronic visual display

devices. The contrast ratio is a dimensionless number, often indicated by adding ':1' to the value of the quotient (e.g. Contrast ratio = 1200:1) (DNP 2015, Kelly et al. 2006, ISO9241 Part3 2008, Ware 2013).

Most commonly luminance is measured using the American National Standards Institute (ANSI) and full-on/ full-off methods (Powell, 2008). The full-on/ full-off method is used to measure the dynamic contrast where an equal size of both black and white is measured (Powell, 2008). The ANSI method is used to measure static contrast using a checker board patterned test image where the black and white luminance values are measured simultaneously (Powell, 2008).

Reading is one of the most important daily visual tasks for patients with visual impairment. Several factors have been identified as affecting the reading performance of patients with visual impairment, including luminance and colour contrast. Legge et al. (1990) found that text can be 'depicted' by changes in character and background luminance i.e. luminance contrast or by differences in chromaticity i.e. colour contrast (Legge et al., 1990). The legibility of reading has been shown to be best predicted by the Michelson contrast definition (MacIntyre and Cowan, 1994).

Manufacturers' descriptions of PELVAs include a contrast enhancement feature, without stating the level of contrast that PELVAs could provide. The aim of this study was to evaluate luminance contrast and to estimate resolution limits that PELVAs provide.

In this study, luminance contrast (under different light levels, viewing modes, viewing conditions for high and low contrast targets) and resolution limit was estimated for 12 PELVAs.

4.2. Laboratory preparation

4.2.1. Illumination

A laboratory was set up for three different illumination conditions: room illumination, dim illumination and dark conditions. The laboratory dimensions (Length x Width) was 4.00 x 3.30 metres. It was divided into 16 small rectangles (Figure 4.1) (Length x Width= 1 x 0.83 metres each) and illumination was measured at the centre of each rectangle using an ETI-8051 light meter (ETI Ltd 2015, www.eti1.co.uk) i.e. illumination meter [ETI-8051 light meter has a measuring range of 0-30,000 lux or 0-2,788 foot candle (fc), 1lux or 0.1 fc resolution, and ±4% accuracy (high accuracy)]. The average of 16 measurements was calculated and represented the illumination level (Metrel 2002, Occupational Safety and Health Branch Labour Department 2008). This procedure was followed to find the illumination level at room illumination, dim illumination, and dark conditions.

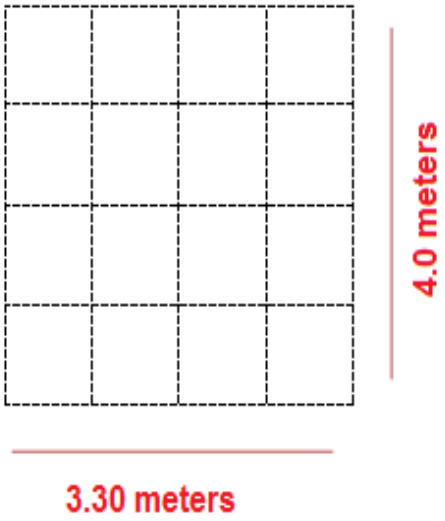


Figure 4.1: Illumination measurements: the laboratory was divided into 16 small rectangles (1 x 0.83 metres each) and illumination was measured at the centre of each rectangle.

4.2.2. Luminance

A luminance meter i.e. Konica Minolta LS-100 luminance-meter (Konica Minolta INC 2015, www.Konica Minolta.com) was used to measure the screen luminance (Figure 4.2). It is a portable spot luminance meter, used for measuring the brightness of light sources in units of candelas per sq. meter (cd/m2). With its minimum focal distance (1,014 mm) it provides 1° field of view and Ø14.4 mm measurement spot size, however with the use of close-up lenses the minimum measuring area can reach to Ø1.3 mm at 205 mm. It provides luminance measurements from 0.001 to 299,900 cd/m². The single-lens-reflex (SLR) optical viewing system allows viewing through the meter to target the required area to be measured. It focuses the lens, on the front of the luminance meter, on the area under test and aligns the black spot over the required area on the light source. This is important to ensure that luminance meters only collect light from the

required area under test and do not receive light from a surrounding area in order to avoid stray light. Stray light can corrupt measurements of the contrast ratio of a display.

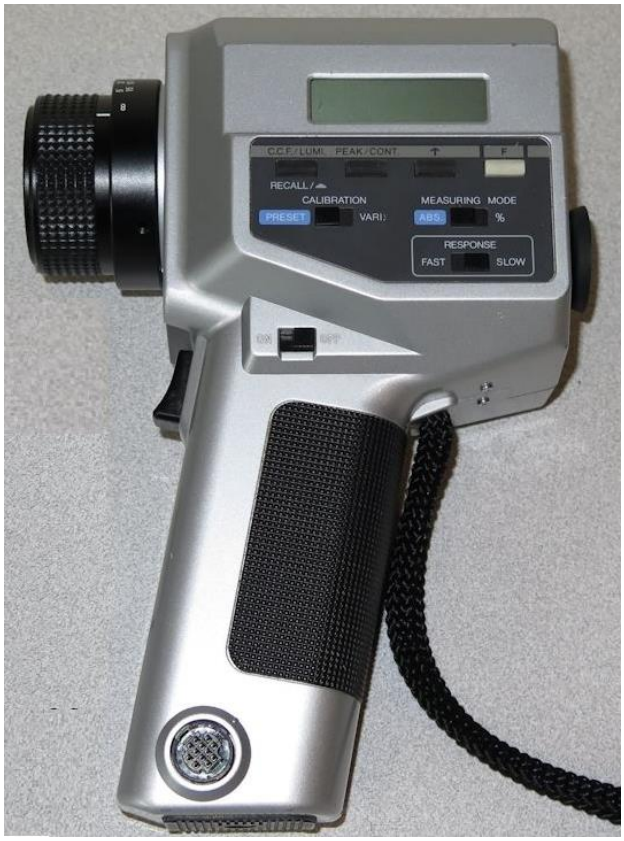


Figure 4.2: Konica Minolta LS-100 luminance meter (Konica Minolta INC, 2015).

4.2.3. Resolution

An ISO 12233 resolution chart (Figure 4.3) was used as a target to estimate the resolution limit of PELVAs. The ISO 12233 Chart is designed to test resolution of electronic still picture cameras. It can be used for testing both monochrome and colour cameras. Targets on this chart can be used to evaluate visual resolution, limiting resolution, and can be used to obtain spatial frequency response (SFR) data (this is

similar to measurements of MTF for a camera). The target resolution ranges from 100 to 2,000 line widths per picture height (Lw/Ph).

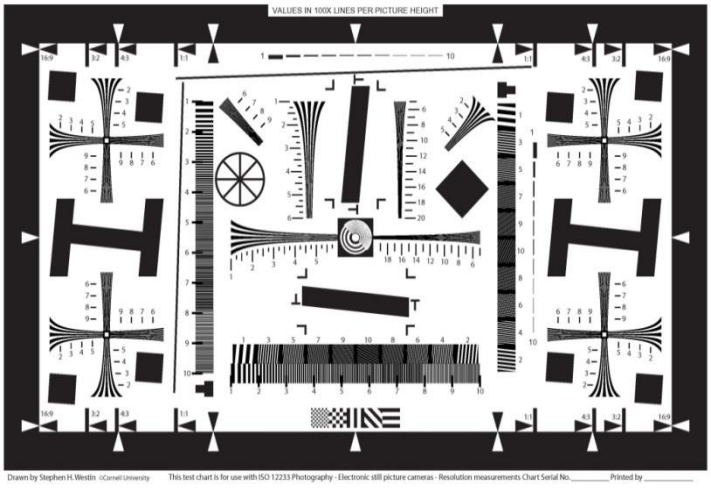


Figure 4.3: ISO 12233 chart http://www.graphics.cornell.edu/~westin/misc/ISO_12233-reschart.pdf (accessed 10 February, 2014).

4.3. Methods

The same set of PELVAs, with the same coding (A-L) that were assessed in Chapter 3 were assessed in this chapter.

4.3.1. Measuring luminance contrast

The luminance contrast was measured for the viewed letter and the background. In order to reduce/ avoid reflection from the white background of a Bailey-Lovie near acuity chart; a black card was covered with black felt. A circular hole was made in the card which was placed over the letter/ background while measuring luminance. The diameter of the hole (4.71 mm) was equal to the width of the viewed letter (sized N80).

The circular hole (Ø 4.71 mm) made it possible to measure the same size of black letter and the white background so that only the required area of black or white was visible at a time.

The viewed letters were a high contrast letter (0.90 Michelson contrast) and a low contrast letter (0.10 Michelson contrast), sized N80 and taken from a Bailey-Lovie near visual acuity chart.

The high contrast letter was viewed using PELVAs under different conditions: 1) three illumination conditions (room (396 lux), dim (12 lux) and dark (0 lux)), 2) different viewing conditions; dynamic (refreshed image) and static (snapshot), and 3) using black-on-white contrast viewing mode and white-on-black contrast viewing mode.

Each PELVA was set at the lowest magnification level, and on the contrast viewing mode, and manufacturer's instructions regarding brightness level were followed.

Maximum and minimum luminance (in cd/m²) of the image obtained by each PELVA was measured using the Konica Minolta LS-100 luminance meter that was fixed and adjusted at 106.5 cm (the distance specified by the manufacturer at which luminance can be detected by the meter) from the PELVA display screen.

Luminance using 12 PELVAs (A-L) was measured with black-on-white contrast viewing mode; the black letter (minimum luminance) on white background (maximum luminance). Due to time constraints on the loan of the devices, the luminance was measured with white-on-black contrast viewing mode for 7 PELVAs (the white letter (maximum contrast) on black background (minimum contrast)). All luminance measurements were repeated 10 times at each illumination level, contrast mode, and viewing condition and the average was recorded.

The luminance contrast using a low contrast letter was measured using 3 PELVAs (B, C, and E) under room and dark illumination conditions; with black-on-white viewing mode and both static and dynamic viewing conditions. At each condition, all luminance measurements were repeated 10 times and the average was recorded.

In this experiment contrast was measured for dynamic and static contrast using a method similar to full-on/ full-off method where only black or only white was visible at a time.

The Michelson contrast equation was applied to calculate the image luminance contrast of each PELVA, at different illumination levels and for static and dynamic viewing modes.

4.3.2. Estimating resolution

The ISO 12233 resolution chart was downloaded in a printable version, and it was printed on high quality photograph papers sized A3, using the maximum number of dots per inch to get a high quality print of this chart. Three different targets (horizontal grating, vertical grating, and diagonal grating) were selected to be viewed by using the PELVAs at three different magnification levels (low, medium and high) (Figure 4.4).

The resolution limit was defined as the area where the first 'fringing' becomes visible. The unit of measurement is Line Width per Picture Height (Lw/Ph).

During resolution measurements, the viewing distance was 40 cm, and magnifiers were placed directly on the chart unless manufacturers recommended a particular angle or distance for best viewing conditions. Horizontal and vertical targets measure resolving power from 100 to 2,000 Lw/Ph.

Diagonal target examine spatial frequency response at different locations. Horizontal, vertical and diagonal oriented wedges are included for comparison of resolving power at various locations.

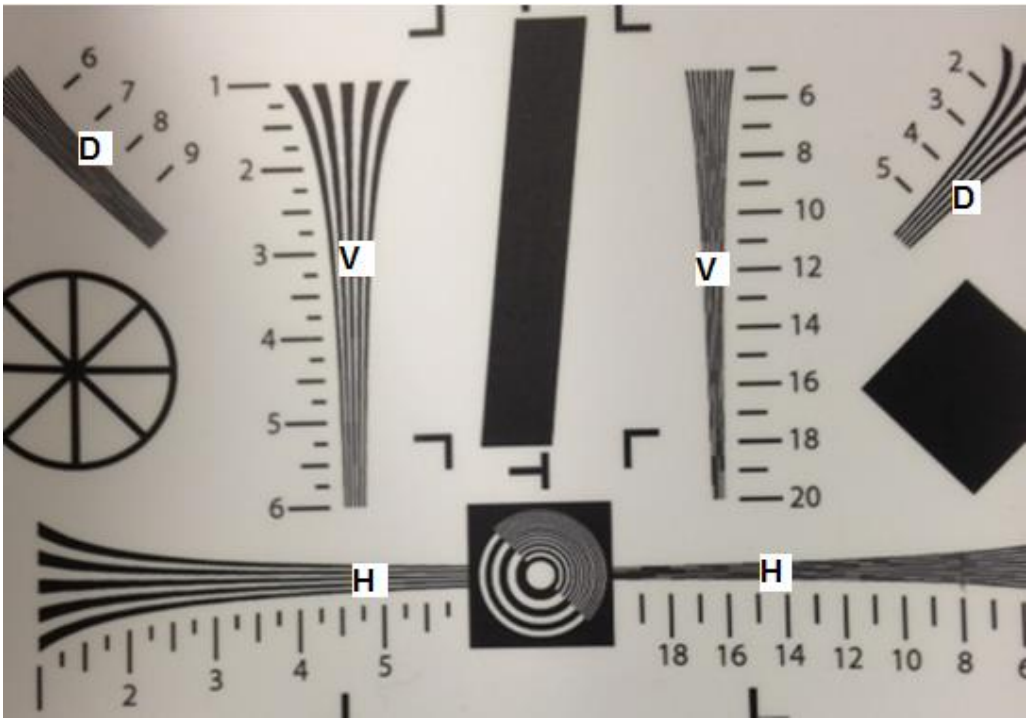


Figure 4.4: Central horizontal (H), vertical (V) and diagonal (D) targets used from ISO 12233 Resolution Chart were used in order to estimate PELVAs limit of resolution.

4.4. Results

Under room illumination (396 lux), the Michelson luminance contrast (as measured on the chart, not through the PELVA) of the high contrast letter was 0.93±0.01, and 0.12±0.01 for the low contrast letter.

4.4.1. Luminance contrast

4.4.1.1. Luminance contrast using a high contrast letter

The dynamic luminance contrast under room illumination of 12 PELVAs is shown in Figure 4.5. All PELVAs (A-L) lie within the minimum recommended luminance contrast ratio of text to background of 3:1 (ISO9241 Part3, 2008) except PELVA (D) (Table 4.1). Only PELVAs (A, B, F, I and K) lie within the preferred contrast ratio of 10:1 (Ware, 2013) (Table 4.1).

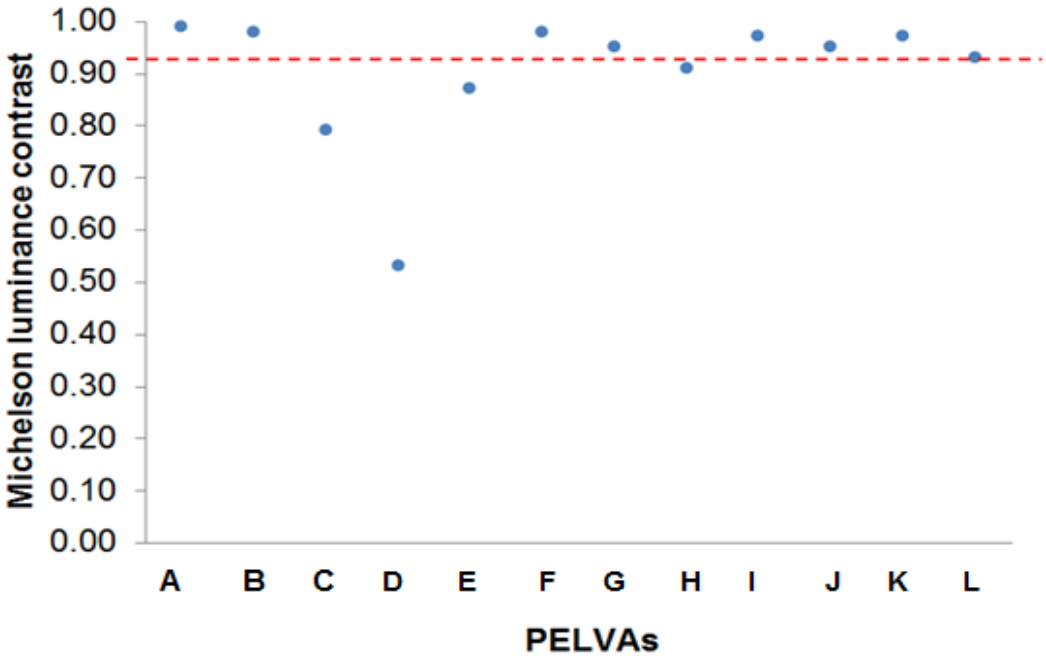


Figure 4.5: The dynamic luminance contrast of 12 PELVAs measured using a high contrast letter with black-on-white viewing mode, under room illumination (396 lux). Horizontal axis represents PELVAs, vertical axis represents the measured luminance contrast; Michelson contrast ranges from 0 to 1, the higher the number the higher the contrast. The dashed line represents the luminance contrast of a high contrast letter (0.93±0.01).

The measured dynamic luminance contrast, with black-on-white viewing mode, of 12 PELVAs under room illumination using a high contrast letter ranged from 0.53 to 0.99 Michelson contrast (Table 4.1). Some PELVAs (A, B, F, G, I, J, and K) enhanced the contrast of the viewed target (Paired sample t-test, $p < 0.05$). On the other hand, other PELVAs (C, D, and E) produced an image with lower contrast than the high contrast letter (Paired sample t-test, $p < 0.05$). The poorest luminance contrast was seen with the PELVA D (Figure 4.5), which was also found to give higher than expected magnification compared to manufacturers reported data (106%). The luminance contrast of the high contrast letter did not change significantly (Paired sample t-test, $p > 0.05$) using PELVAs

(H and L) although the luminance contrast of PELVA H was slightly lower compared to the high contrast letter.

4.4.1.2. Different illumination conditions, using a high contrast letter

The measured luminance contrast of 12 PELVAs under different illumination conditions is shown in Table 4.1. There were no significant differences (ANOVA: $F = 1.287$ $p > 0.05$, Multiple paired sample t-test $p > 0.05$) between luminance contrast measured under three different illumination conditions, using a high contrast letter with black-on-white viewing mode, for 12 PELVAs. The mean difference in measured luminance contrast under three illumination conditions (room, dim, and dark) was 0.01±0.005 Michelson contrast (ANOVA, $p > 0.05$). PELVA D showed the poorest contrast among all PELVAs at all illumination levels (Table 4.1). All PELVAs, except D, lie within the ISO9241 Part 3 (2008) standard for all illumination conditions. The discrepancy in PELVA D we could not explain. However, manufacturing or technical faults cannot be excluded because the same PELVA did not fall within ISO15253:2000 standard (BSI, 2000) for magnification tolerance.

PELVA	Static				Dynamic				Contrast Ratio *	Ware 2013 standard	ISO9241, Part 3 2008 standard
	Room Mean±SD	Dim Mean±SD	Dark Mean±SD	P-value	Room Mean±SD	Dim Mean±SD	Dark Mean±SD	P-value			
A	0.92±0.004	0.86±0.021	0.93±0.006	0.448	0.99±0.001	0.97±0.002	0.99±0.005	0.365	13.0:1	✓	✓
B	0.99±0.019	0.96±0.024	0.91±0.011	0.791	0.98±0.018	0.97±0.001	0.97±0.026	0.449	12.7: 1	✓	✓
C	0.70±0.023	0.72±0.032	0.78±0.009	0.100	0.79±0.009	0.8±0.009	0.84±0.030	0.441	7.3:1	X	✓
D	0.41±0.006	0.22±0.003	0.22±0.002	0.123	0.53±0.010	0.38±0.012	0.37±0.004	0.779	2.3:1	X	X
E	0.85±0.019	0.82±0.001	0.67±0.003	0.440	0.87±0.003	0.85±0.019	0.79±0.032	0.281	8.9:1	X	✓
F	0.95±0.002	0.94±0.002	0.95±0.014	0.630	0.98±0.001	0.99±0.032	0.99±0.01	0.231	10.2:1	✓	✓
G	0.88±0.022	0.88±0.040	0.88±0.001	0.978	0.95±0.001	0.95±0.007	0.95±0.003	0.742	9.4:1	X	✓
H	0.86±0.005	0.91±0.020	0.91±0.021	0.340	0.91±0.019	0.97±0.002	0.97±0.021	0.812	9:1	X	✓
I	0.92±0.037	0.91±0.011	0.93±0.003	0.430	0.97±0.007	0.97±0.001	0.96±0.019	0.090	11:1	✓	✓
J	0.88±0.023	0.92±0.001	0.93±0.002	0.080	0.95±0.004	0.95±0.015	0.96±0.021	0.562	9.3:1	X	✓
K	0.94±0.005	0.92±0.009	0.90±0.005	0.054	0.97±0.013	0.96±0.004	0.97±0.002	0.771	10.0:1	✓	✓
L	0.75±0.003	0.81±0.002	0.94±0.013	0.440	0.93±0.002	0.90±0.016	0.99±0.005	0.234	9.0:1	X	✓

Table 4.1: The Michelson luminance contrast (the mean and standard deviation of 10 measurements) of 12 PELVAs (A-L), measured under different illumination conditions (room, dim, and dark) using a high contrast letter (0.93±0.01 Michelson contrast) with black-on-white viewing mode, with static and dynamic viewing conditions. P-value (ANOVA) is significant if < 0.05. * Contrast ratio = Background luminance/ Letter luminance, as measured under room illumination with dynamic mode. ✓ PELVA's contrast ratio lie within the standard. X PELVA's contrast ratio did not lie within the standard.

4.4.1.3. Dynamic versus static viewing condition

The measured luminance contrast with both dynamic and static viewing conditions using a high contrast letter with black-on-white viewing mode is shown in Table 4.1, and Figures 4.6 and 4.7. The measured luminance contrast of 12 PELVAs was significantly higher using the dynamic viewing condition compared to the static viewing condition under all illumination conditions. The mean measured luminance contrast using the dynamic viewing condition was 0.89±0.16 Michelson contrast compared to 0.83±0.18 Michelson contrast using the static viewing condition (Paired sample t-test, $p < 0.001$).

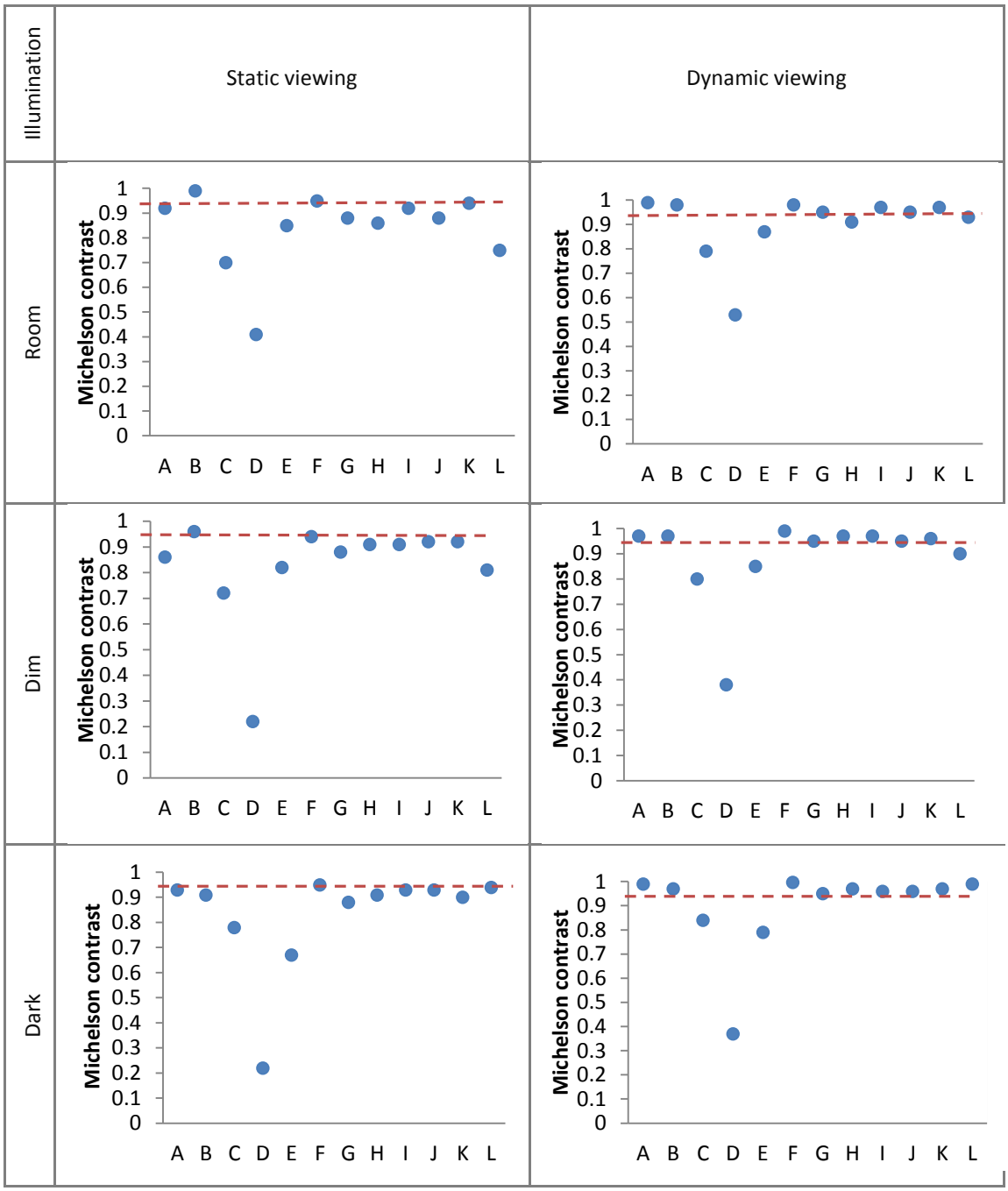


Figure 4.6: The dynamic luminance contrast compared to the static luminance contrast of 12 PELVAs (A-L) under different illumination (room, dim, and dark) using a high contrast letter chart with black-on-white viewing mode. The horizontal axis shows 12 PELVAs (A-L). The vertical axis (dots) shows the Michelson contrast. The dashed line shows the luminance contrast of the high contrast letter (0.93 Michelson contrast). The poorest contrast was for PELVA D using both static and dynamic viewing under all illumination conditions.

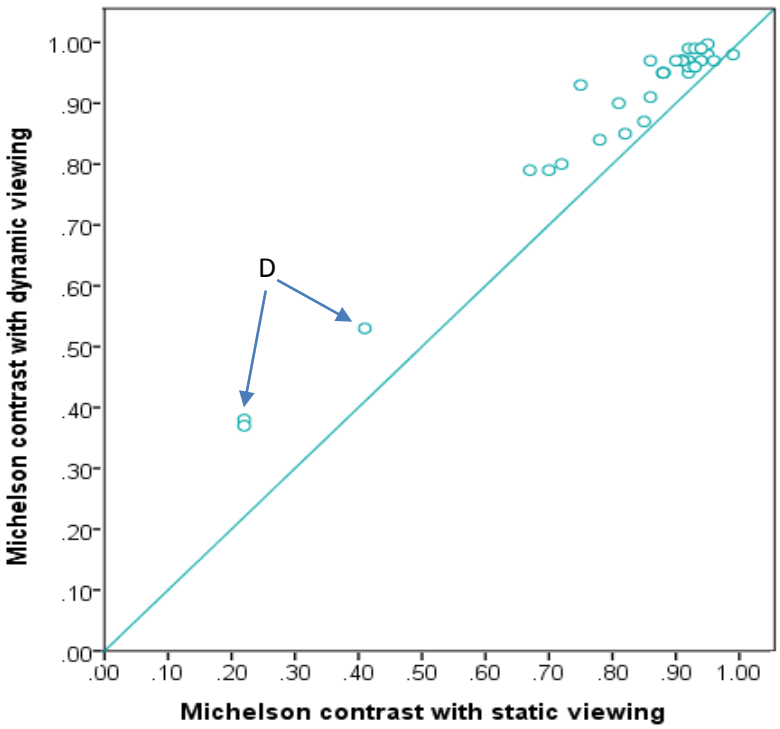


Figure 4.7: The luminance contrast of 12 PELVAs with dynamic viewing compared to the luminance contrast with static viewing conditions using a high contrast letter with black-on-white viewing mode (all lighting levels). The graph shows that dynamic contrast was higher than static contrast; most circles are clustered above the reference line. Arrows: The outlier (outside the standard of Ware 2013 and the ISO9241 Part 3 (2008) standard) was PELVA D, under different illumination conditions, as shown in Table 4.1. PELVA D also showed the poorest contrast at all illumination levels.

4.4.1.4. Luminance contrast with black-on-white viewing mode versus luminance contrast with white-on-black viewing mode

A comparison between luminance contrast using black-on-white viewing mode and luminance contrast using white-on-black viewing mode (contrast reverse/ polarity) is shown in Figure 4.8 and Table 4.2. There were no significant differences between luminance contrast of any of the 7 PELVAs measured with black-on-white viewing mode and white-on-black viewing mode using a high contrast letter. The mean difference

between measured luminance using black-on-white and white-on-black viewing mode was 0.008±0.03 Michelson contrast (Paired sample t-test, p = 0.600).

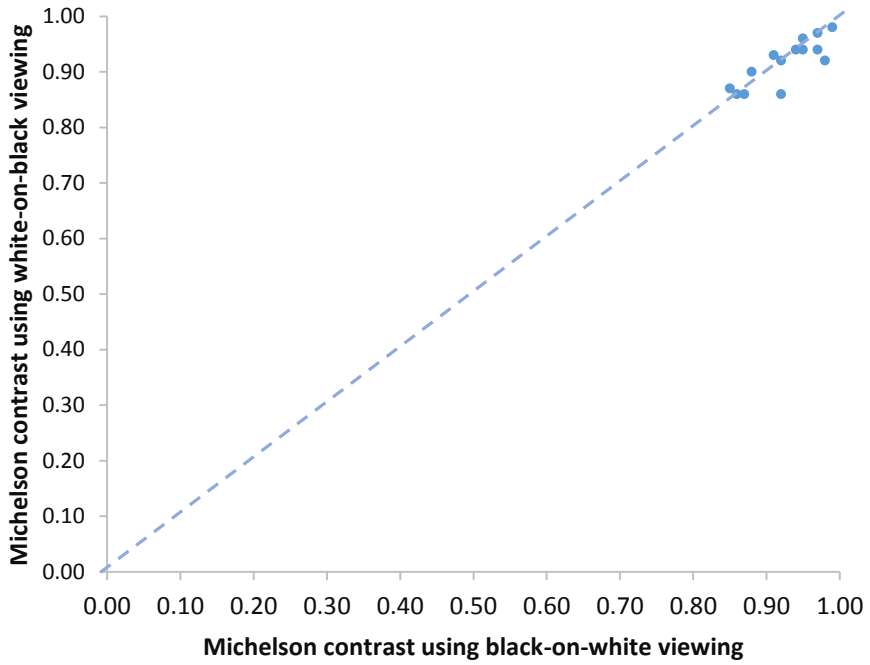


Figure 4.8: The Michelson luminance contrast of 7 PELVAs using black-on-white viewing mode compared to the Michelson luminance contrast using white-on-black viewing mode, using a high contrast letter. Data points are the mean of 10 measurements. Most points cluster close to the reference line.

	PELVAs	Black-on-white (Mean±SD)	White-on-black (Mean±SD)
Static	A	0.92±0.004	0.92±0.03
	E	0.85±0.019	0.87±0.02
	F	0.95±0.002	0.94±0.04
	H	0.86±0.005	0.86±0.08
	I	0.92±0.037	0.86±0.20
	J	0.88±0.023	0.90±0.03
	K	0.94±0.005	0.94±0.02
Dynamic	A	0.99±0.001	0.98±0.01
	E	0.87±0.003	0.86±0.01
	F	0.98±0.001	0.92±0.02
	H	0.91±0.019	0.93±0.01
	I	0.97±0.007	0.97±0.05
	J	0.95±0.004	0.96±0.03
	K	0.97±0.013	0.94±0.08

Table 4.2: The Michelson luminance contrast (mean and standard deviation (SD) of 10 measurements) of 7 PELVAs using black-on-white viewing mode compared to luminance contrast using white-on-black viewing mode, using a high contrast letter.

4.4.1.5. Luminance contrast using a low contrast letter

Some PELVAs improved the luminance contrast of a high contrast letter; in order to find whether PELVAs improve the contrast of a low contrast object, luminance contrast was measured for a low contrast letter. The Michelson luminance contrast of the low contrast letter was 0.12±0.005 under room illumination (396 lux).

Table 4.3 shows the luminance contrast measured for 3 PELVAs (B, C, and E), these were same PELVAs used in the previous experiments, using the low contrast letter (0.12 Michelson contrast) with contrast viewing mode (black-on-white), using dynamic and static viewing conditions. Three PELVAs only were used to measure the luminance contrast of a low contrast letter because of time constraints on the loan of the devices.

We had PELVA B at the School of Optometry, PELVAs C and E that were on extended loan, and all other PELVAs had to be returned to the suppliers.

The luminance contrast of PELVAs of a low contrast letter (0.12 Michelson contrast) using PELVAs was significantly increased (almost doubled) ($p < 0.05$), with both static and dynamic viewing conditions under different illumination conditions (room and dark illumination). The measured luminance contrast using a low contrast letter ranged from 0.24 to 0.26 Michelson contrast using the dynamic viewing condition and from 0.19 to 0.22 using the static viewing condition (Table 4.3).

The luminance contrast did not appear even across the screen, and a better contrast was seen at the middle of the screen. The measured luminance contrast in this study reflects the luminance contrast of the central area of PELVAs display screen.

	Static			**Dynamic**			**Static vs. dynamic**
PELVA	**Room Mean±SD**	**Dark Mean±SD**	**P-value**	**Room Mean±SD**	**Dark Mean±SD**	**P-value**	**P-value[1]**
B	0.21±0.001	0.22±0.013	0.068	0.25±0.001	0.26±0.002	0.128	<0.001*
C	0.19±0.002	0.21±0.010	0.789	0.25±0.021	0.25±0.030	0.327	<0.001*
E	0.20±0.002	0.21±0.001	0.536	0.24±0.011	0.24±0.001	0.459	<0.001*

Table 4.3: The Michelson luminance contrast (mean and standard deviation (SD) of 10 measurements) of 3 PELVAs using a low contrast letter (0.12±0.01 Michelson contrast) under different illumination and viewing condition with black-on-white contrast viewing mode. P value: Paired sample t-test. P-value[1] shows the significance of the mean difference between static and dynamic viewing under room and dark conditions combined.

There was no significant difference in the measured luminance contrast using a low contrast letter at different illumination conditions (room and dark). The mean difference in luminance contrast between room and dark conditions was 0.013±0.006 Michelson contrast with static viewing (Paired sample t-test, $p > 0.05$), and 0.005±0.005 Michelson contrast with dynamic viewing (Paired sample t-test, $p > 0.05$) (Table 4.3). Luminance contrast under dim illumination was not measured in this experiment because there was no difference in luminance contrast under different illumination conditions in the previous experiment.

The dynamic luminance contrast was significantly higher than static luminance contrast using a low contrast letter (Table 4.3). The mean Michelson luminance contrast for room and dark conditions combined with the dynamic viewing condition was 0.25±0.008 and 0.21±0.01 for the static viewing condition (Paired sample t-test, $p < 0.001$).

Although the luminance contrast of PELVAs (B, C, and E) significantly increased (0.19-0.26 Michelson contrast) using a low contrast letter, it still far a long way short of the luminance contrast (0.67-0.99) using a high contrast letter.

4.4.2. Estimated resolution using ISO 1233 chart

The estimated resolution limit that each PELVA (A - L) could provide using three different targets (horizontal, vertical, and diagonal) from an ISO 12233 chart, under different

magnification levels (the lowest, medium, and the highest magnification levels) in 100 Lw/Ph is shown in Table 4.4.

The resolution of the targets on the ISO 12233 chart ranges from 1*100 to 20*100 Lw/Ph. In general, the spatial resolution of computer monitors is 72 to 100 lines/ inch; this is equivalent of 8.5*100 to 16.5*100 Lw/Ph if the test chart A3 size is used. This means any PELVA that provided a resolution within this range can be comparable to a computer screen; the higher the resolution is better.

Applying this on the diagonal target resolution which is the best predictor of screen performance (Bond, 2015), only PELVAs (B, C, F, G and L) provided a resolution equal to or better than 8.5*100 Lw/Ph (i.e. comparable to a general computer screen). A horizontal or vertical line of a specific pixels length covers a specific linear distance on the display screen but this is different for diagonal lines; in which the same number of pixels covers a larger linear distance on the display screen. This could be up to 40% larger in some displays and may affect the diagonal lines by making them fainter by up to 30% (aliasing) (Bond, 2015).

PELVA	Average resolution at different magnification levels *100			Average resolution using different targets *100		
	High magnification	Medium magnification	Low magnification	Horizontal grating target	Vertical grating target	Diagonal grating target
A	9.8	8.5	7.3	9.6	9.0	7.0
B	11.6	10.2	9.16	12.1	10.3	8.5
C	14.3	13.6	12.6	16.6	15	9.0
D	13.1	9.6	6.3	11.0	10.6	7.5
E	8.5	7.0	7.0	7.0	8.5	7.7
F	11.6	10.8	9.5	12.3	10.1	9.5
G	14.1	13.1	11.3	14.8	14.6	9.1
H	11.5	8.8	6.3	11.6	8.3	6.6
I	9.8	7.6	6.0	7.1	9.3	7.0
J	10.6	9.6	8.6	11.0	10.0	8.0
K	6.3	5.6	5.0	5.8	5.5	5.6
L	11.6	10.6	9.6	12.3	11.0	8.8

Table 4.4: The estimated resolution limit of 12 PELVAs (A - L) using three different targets (horizontal grating target, vertical grating target, and diagonal grating target) from ISO 12233 resolution chart (Values in 100 Lw/Ph).

The mean estimated resolution limit using horizontal grating target was 10.9*100±3.2 Lw/Ph (range 5.8*100-16.6*100). The mean estimated resolution limit using vertical grating target was 10.2*100±2.6 Lw/Ph (range 5.5*100-15*100). The mean estimated resolution limit using diagonal grating target was 7.9*100±1.2 Lw/Ph (range 5.6*100-9.5*100).

The poorest resolution (the outliers in Figures 4.9 and 4.10) was found using PELVA K; this might be because of its low cost compared to most PELVAs, which may suggest a poorer quality display screen. PELVA K also had lower than expected magnification.

The estimated resolution limits using diagonal grating target was significantly lower than estimated resolution limits using both horizontal and vertical grating targets (ANOVA: $F = 102.670$, $p < 0.05$) which was expected due to aliasing of diagonal target. There were no statistically significant differences (ANOVA: $F = 1.932$, $p > 0.05$) in the estimated resolution limits between horizontal and vertical grating targets (Figure 4.9).

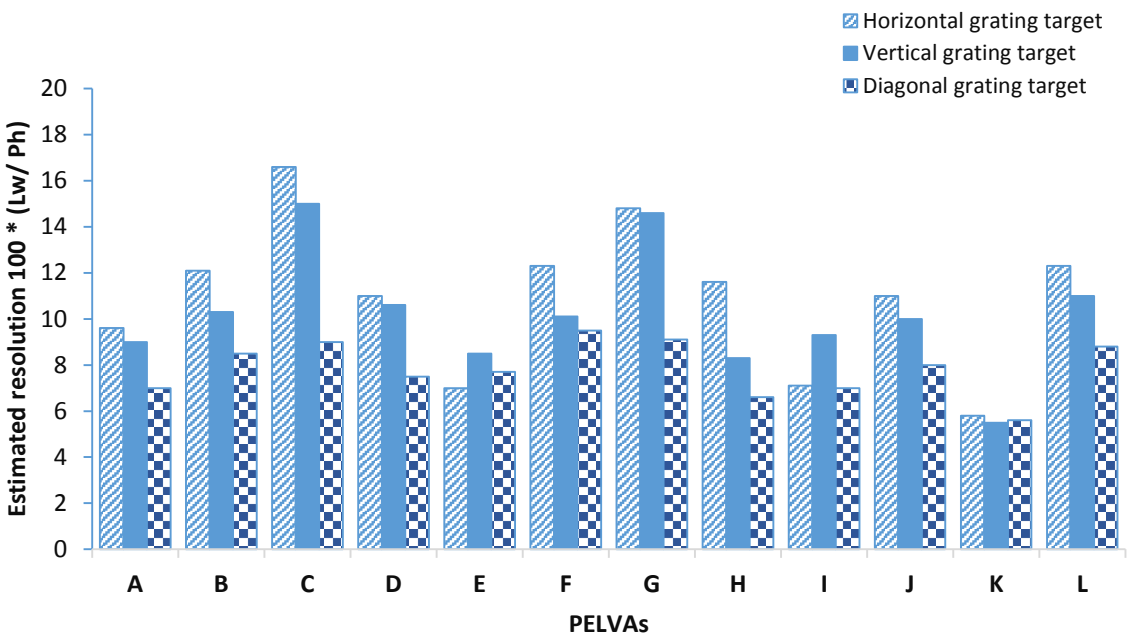


Figure 4.9: The estimated resolution limit in 100*Lw/Ph of 12 PELVAs using 3 different grating targets (horizontal, vertical, and diagonal); showing a lower resolution limit using the diagonal grating target. The poorest resolution was for PELVA K.

In terms of magnification, there was a variation between resolution and magnification between different magnifiers (Figure 4.10). The resolution was significantly higher (better) with increasing magnification. The mean difference in the estimated resolution limits between higher and medium magnification was 1.48*100±0.88 Lw/Ph, and

between medium and lower magnification was 1.36*100±0.87 Lw/Ph. This was not expected; as with higher magnification the sharpness of targets edges deteriorated and pixilation was more obvious compared to medium and lower magnification levels. Moreover, the difference that magnification made on resolution varied between magnifiers and was not uniform.

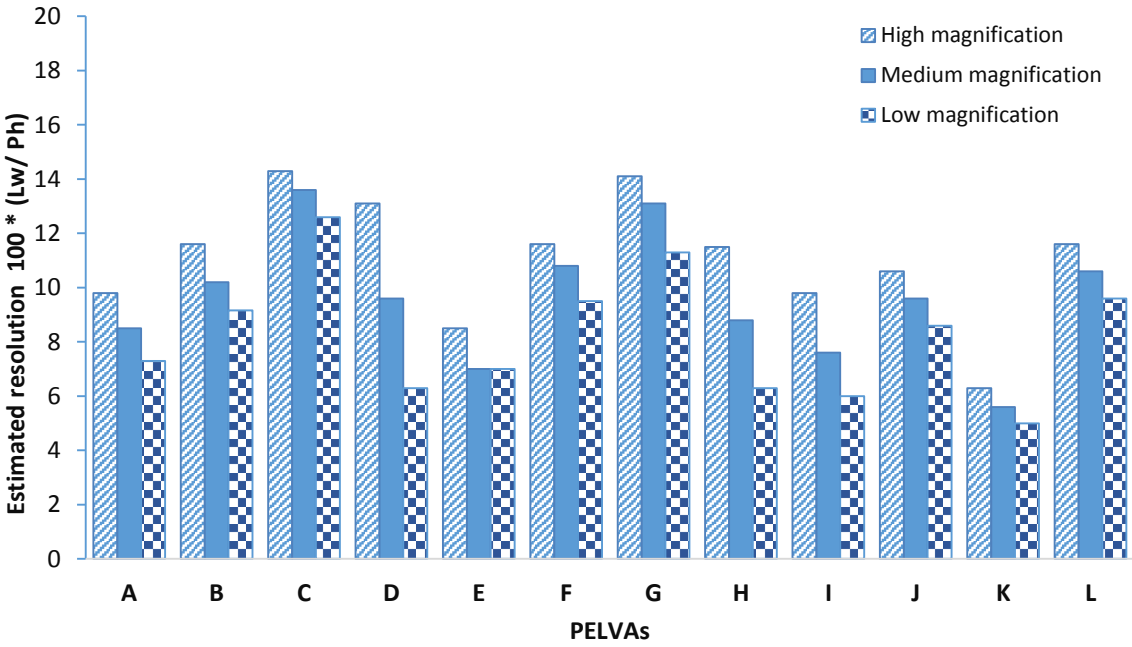


Figure 4.10: The estimated resolution limit in 100*Lw/Ph of 12 PELVAs under different magnification levels (high, medium, and low); showing a higher resolution limit under the high magnification level. The poorest resolution was for PELVA K.

4.5. Discussion

Luminance contrast of 12 PELVAs (A- L) was measured in an independent setting (dynamic viewing condition, under room illumination, and using black-on-white contrast viewing mode, which is the conventional settings of PELVAs use) using a high contrast letter (0.93 Michelson contrast). Only seven PELVAs (A, B, F, G, I, J and K) significantly improved the luminance contrast for the high contrast letter. The measured luminance contrast of the high contrast letter was reduced significantly for PELVAs (C, D, and E), and was about the same for two PELVAs (H and L).

All PELVAs (A- L) lie within the minimum recommended background to letter contrast ratio (Contrast ratio = Highest luminance/ Lowest luminance) of 3:1 (ISO9241 Part3, 2008) except PELVA D which was also found to give higher than expected magnification compared to manufacturers reported data (106%); this might be explained by manufacturing error, or technical faults. Only PELVAs (A, B, F, I, and K) lie with the preferred contrast ratio (contrast ratio = Highest luminance/ Lowest luminance) (Ware, 2013) of 10:1 Table (4.1).

Crossland et al. (2010) found that the Michelson contrast for Sony and Kindle readers were 63% and 62% respectively. All PELVAs in this study except PELVA (D) had significantly better Michelson Luminance contrast compared to Sony and Kindle readers.

The luminance contrast of images obtained by EVES that were used in the Peterson et al. (2003) ranged between 0.70 and 0.90 (Michelson contrast). The Michelson luminance

contrast of all PELVAs under three illumination conditions and using static and dynamic viewing (0.70-0.99) was equal to or better than the luminance contrast of EVES [except PELVA D under all illumination conditions using static and dynamic (0.22-0.53), and PELVA E under dark illumination using static viewing (0.67)].

This study found that the luminance contrast of a high contrast letter viewed by PELVAs was 1) not affected by different illumination conditions, 2) significantly higher using the dynamic viewing compared to static viewing conditions, 3) not significantly different using white-on-black viewing compared to black-on-white viewing modes.

Luminance contrast was measured in different illumination. Room illumination is the illumination that most people read with; dark conditions in order to measure the actual luminance of the letter and the background in order to exclude the effect of surrounding illumination; dim illumination because not all people use the devices in an ideal room illumination or day illumination and it is known that ambient light can affect the brightness or the luminance of a screen. The actual luminance contrast can be obtained in dark conditions (with absolutely no other light source). In this study, there was no specific pattern to predict in which illumination level PELVAs performed best; there was no significant difference in luminance contrast between three illumination conditions.

The difference between dynamic and static contrast was expected due to the fact that in dynamic viewing the image is refreshed continuously several times per time unit (for example, a movie projector runs 24 frames per second, each frame is illuminated two or

three times before the next frame is projected, giving a refresh rate of 72 Hertz) and the maximum and minimum luminance of background and letter is measured over time. In comparison, in static viewing in which the snapshot cannot be refreshed again, the luminance is measured every time at one point, and the maximum and minimum luminance is measured simultaneously. The refresh rate of PELVAs was not included with their descriptions, but the refresh rate of desktop video magnifiers is about 60 frames per second (Digital Apex, 2015).

Overall, there was no significant difference between black-on-white contrast and white-on-black contrast. Zabel et al. (1982) found that the blur perceived using EVES systems when moving black-on-white print (because of update rate or refresh rate) is increased by white-on-black print. Although white-on-black increases perceived blur, it has the advantage of reduced glare and less picture flicker (Zabel et al., 1982). Therefore, preference for white-on-black is an individual preference (Legge and Rubin 1986, Jacobs 1990). Mehr et al. (1973) reported a preference for white-on-black over black-on-white print. However, some studies (Zabel et al., 1982) reported an equal preference for both types of print, with 70% preferring contrast-enhanced print (Zabel et al., 1982).

Finding that some PELVAs could improve the luminance contrast of a high contrast text, only slightly; it was important to find if the use of PELVAs is more beneficial for a low contrast text compared to a higher contrast text. Therefore, the luminance contrast using a low contrast letter was measured for 3 PELVAs.

It was found that the luminance contrast of 3 PELVAs using the low contrast letter was increased (almost doubled). This might suggest that PELVAs could be more beneficial for patients with a visual impairment for tasks involving lower contrast targets/ scenes. However, although the contrast was doubled this was still only 0.19 to 0.26 Michelson contrast compared to 0.67-0.99 Micheslon contrast using a high contrast letter. So, for people with very much reduced contrast sensitivity it may not improve it enough.

All luminance measurements were repeated 10 times at each illumination, contrast, and viewing condition and the average was recorded. The luminance measurements were repeated due to possible variations in luminance readings which might be attributed to the small hole size (positioning of the luminance meter spot directly over the circular hole), exposure time (the time taken to take the luminance measurement), and the amount of reflected light from the PELVA light source (Konica Minolta INC, 2013). The variation between measurements ranged between 0.00 and 2.09 cd/m².

The resolution is an important determinant of image quality. Therefore, the resolution limits of 12 PELVAs (A-L) were also investigated in this study.

Because of the fact that PELVAs are designed to be used at a very close distance from the viewed target and some of them should be placed directly on the viewed target it was difficult to get an image of the whole chart using PELVAs. Hence, three targets with different grating directions were chosen from the chart to be viewed by PELVAs in order to find their resolution limits.

Three targets with different grating directions (horizontal, vertical, and diagonal) were chosen in order to estimate the pixilation on each direction. In manufacturing a display the diagonal and horizontal or vertical lines will be treated the same so they have the same brightness at each pixel; but this would result in a less uniform density of colours. This is because a horizontal or vertical line of a specific pixels length covers a specific linear distance on the display screen but this is different in terms of diagonal lines; in which the same number of pixels covers a larger linear distance on the display screen. This could be up to 40% larger in some displays and may affect the diagonal lines by making them fainter by up to 30% in some screens (Bond, 2015). Horizontal, vertical and diagonal grating targets are included for comparison of resolution at different locations on the screen.

The poorest resolution was for PELVA K which had also lower than expected magnification, with up to 72% deviation from the ISO standard for magnification tolerance. This might be due to its low cost compared to most PELVAs, or it might be attributed to a poor quality display screen.

There was no significant difference in the resolution limits using horizontal and vertical targets. The estimated resolution limit was significantly lower using the diagonal grating target compared to both horizontal and vertical which was expected due to aliasing of diagonal target.

The estimated resolution limits were significantly higher with higher magnification. This was not expected; it could be because of the brightness of the screen made targets details still clear even at higher magnification. Also, in this study resolution limit was defined as the first seen merging of two lines. Although, with higher magnification the sharpness of targets edges deteriorated and pixilation was obvious compared to medium and lower magnification levels.

Resolution limit estimates were subjectively estimated. These could be more accurate if software (called SFRplus) was used rather than depending on subjective assessment. SFRplus/ IMAtest measures the modulation transfer function (MTF) over the whole image plane as well as many other image quality factors such as resolution. The software is very expensive; costing about £7,000 (IMAtest LLC, USA www.imatest.com).

This experiment illustrated how it is important to examine low vision aids actual parameters, in order to assess what they might do for patients with visual impairment. Luminance contrast of PELVAs included in this experiment was overall good, with some exception as mentioned in results section.

The limitations of this study were that only one observer measured the luminance contrast and estimated the resolution limits of PELVAs. The luminances contrast of the PELVAs were not reported by manufacturers, so we could not compare those with the PELVAs luminance contrast measured in an independent setting. No information was available about manufacturers' methods of evaluating contrast and resolution of

PELVAs. We contacted the manufacturers regarding the techniques/ methodology used, but we had no replies. Therefore, the method used in this study may differ from these employed by the manufacturers. The luminance contrast of the low contrast letter was measured using only three PELVAs due to time constraints on the loan period for PELVAs. It might be important in the future to measure luminance contrast and resolution with more than one observer, using different manufacturers' methods for evaluating contrast and resolution, and using SFRplus software for measuring resolution, and using more PELVAs. Moreover, because the luminance contrast appeared to vary across the screen with a better image obtained at the middle of the screen, we measured the luminance contrast only at the middle of the screen. Therefore, it would be important to measure the luminance contrast across the screen in a follow-up study.

4.6. Conclusion

Some PELVAs significantly improved the contrast of a high contrast letter; whilst others significantly reduced the contrast. All PELVAs (A-L) lie within the minimum recommended luminance contrast ratio of text and background of 3:1 (ISO9241 Part3, 2008) except one PELVA (D). Only PELVAs (A, B, F, I, and K) lie within the preferred contrast ratio by Ware (2013) of 10:1.

Illumination conditions had no significant effect on the luminance contrast of PELVAs. There was no significant difference for different contrast viewing modes (black-on-white and white-on-black) on the luminance contrast of PELVAs. The dynamic viewing conditions (refreshed image) had an advantage over the static viewing conditions in terms of significant increase of luminance contrast.

For a patient with reduced contrast sensitivity, such as a patient with cataract, glaucoma, or diabetic retinopathy, a PELVA would be useful to improve a low contrast scene or target. This is an advantage that PELVAs have compared to the conventional low vision aids.

The contrast of a low contrast letter was almost doubled using some PELVAs, although the contrast was not the same as a high contrast letter. So, for people with severe reduction in contrast sensitivity it may not improve it enough.

PELVAs (B, C, F, G and L) provided an estimated resolution limit of greater than or equal to 8.5*100 Lw/Ph (i.e. the resolution of a general computer screen). High resolution is an important factor to maintain a good quality image, particularly for patients with a visual impairment.

CHAPTER 5: The clinicians' prescribing patterns for pocket and portable electronic low vision aids for patients with a visual impairment who attended the Low Vision Service Wales

5.1. Introduction

As discussed in Chapter 2, very few studies (Lighthouse National Survey on Vision Loss 1995, Crossland and Silver 2005, Nguyen et al. 2009) have assessed the prescribing patterns for low vision aids, and to date no one has evaluated the prescribing patterns for PELVAs.

Schurink et al. (2011) reported that even though there are several types of low vision aids, their prescription and use were low in visually impaired children. Although some research has investigated the use of low vision aids among children (Corn et al. 2002, Ruddeck et al. 2004), little is known about their use in the low vision population as a whole. In addition, there is little information about the type of these devices in relation to the type of visual impairment (Leat 2002, Corn et al. 2002, Ruddeck et al. 2004, Lennon et al. 2007, Haddad et al. 2009, Schurink et al. 2011*).* For example, Haddad et al. (2009) found that 36% of children used optical low vision aids for distance, and 6% used optical low vision aids for near, monocular telescope and stand magnifiers were the most prescribed aids. Lennon et al. (2007) found that 69% of children used optical low vision aids for near (brightfield magnifier was the most commonly prescribed aid). A proportion of 25% of children were prescribed low vision aids (a CCTV, telescopes, hand-held and stand magnifiers, brightfield magnifiers) and 82.7% of them used their devices on a regular basis, in the Ruddeck et al. (2004) study.

Wolffson and Peterson (2003) suggested that the increased demand for electronic low vision aids, particularly CCTVs and their simplicity have made them more frequently considered in clinical practice (Wolffson and Peterson, 2003).

The American Optometric Association (AOA) recommended that the severity and stability of the underlying visual impairment should be considered when prescribing low vision aids, and the prescription of optical low vision aids might be better delayed until the visual impairment become more stable (Freeman et al., 2007). AOA also considered that a 'loaner system' of low vision aids is invaluable, particularly for patients with unstable visual impairment (Freeman et al., 2007).

It is important to understand the prescribing patterns for available low vision aids, such as PELVAs, and to determine which patients are most likely to benefit from these devices, in addition to what factors might affect the prescribing for PELVAs. To date there was no published literature that describes the prescribing patterns for PELVAs. One PELVA (Compact+) has been available on loan for patients with visual impairment attending the Low Vision Service Wales (LVSW) [a National Health Service (NHS) in Wales] (Charlton et al. 2011, Taylor et al. 2014).Therefore, the aim of this study was to assess a data set of patients who attended the LVSW in the year 2011/2012 in order to determine the prescribing patterns for PELVAs.

5.2. Methods

Data from 7,866 records of patients who attended 187 LVSW clinics across Wales in the year 2011/2012 (the period between 1st April 2011 and 31st March 2012) were reviewed and analysed using SPSS 20.0.

5.2.1. Data recording and preparation

Accredited practitioners recorded biographical and clinical information on standard record cards. Patients were required to sign the record and indicate if they were happy for their information to be used for research and/ or audit purposes. Practitioners sent the signed records by secure fax to the NHS central service administration. Key data from the records were incorporated into a computerised data set.

Data set

The required data set was downloaded from the service data set by the LVSW manager. It was then sent to us as an Excel spreadsheet. A sample of the data set is shown in Appendix I. All data were manually transferred into an SPSS 20.0 file, so that numbers of patients falling into each category could be analysed. The data set included demographic and clinical information of patients which was limited to: 1) age, 2) gender, 3) type of visit (follow up or assessment), 4) living situation (with partner, with other people, sheltered accommodation, residential care, or alone), 5) registration of visual impairment (severely sight impaired, sight impaired, or not registered), 6) ocular condition, 7) binocular distance visual acuity, 8) binocular near visual acuity, and 9) prescribed a Compact+ (Yes/ No).

Limitations of the data set

Although clinicians record the visual acuity using Log Minimum Angle of Resolution (Log MAR) charts, binocular distance visual acuity was recorded in the service data set in Snellen 6 metres notation. Therefore, distance visual acuity was converted into Log MAR.

Data about near visual acuity were not used in this study, because information about the test chart used, the spectacles worn and viewing distance were not included in the data set.

Causes of visual impairment for common conditions were ticked by practitioners on patients' record cards. Often there were a number of conditions, but the principal cause of visual impairment was not identified in their records.

The data set provided by the service included information about whether a patient was prescribed a PELVA or not. It did not include information about other types of low vision aids that were prescribed, or if patients who were not prescribed a Compact+ were prescribed other aids. Therefore, the 'prescribed a PELVA' group may contain patients who were also prescribed other aids. Moreover, we could not filter out patients who were not prescribed any low vision aids.

Contrast sensitivity, although on the record card, was not recorded on the service data set.

Full records were not available for follow-up patients. Therefore, records from patients who had a follow-up visit with low vision aids prescribed and an assessment record in the same year (882 records) were merged in the data set. This resulted in a total of 6,984 records.

After review, 316 patient records were removed; those were records from follow-up visits for which no assessment visit information was available because they had been seen for assessment in the preceding year. A total of 6,668 records remained.

5.2.2. Ethics

Ethical approval was obtained as part of the on-going audit process of the service and all procedures followed the Declaration of Helsinki.

5.2.3. Statistics

Testing for normality of the data set was performed in order to choose the appropriate statistical test [SPSS: analyse ➔ descriptive statistics ➔ explore ➔ descriptives and percentiles (confidence interval 95%) ➔ normality plots with statistics]. Shapiro-Wilk test of normality is used for small sample sizes of up to 2,000 subjects; because of the large sample size > 2,000 in this study (n=6,668) Kolmogorov-Smirnov normality test was chosen.

Descriptive statistics and frequencies were performed for the whole data set (including: mean, standard deviation, median, range, interquartile range, minimum and maximum values, variance, etc. as where appropriate) for all variables/ factors in the data set, in order to describe the demographics of the patients.

The data were then split into two groups: first group: prescribed a PELVA; second group: not prescribed a PELVA [SPSS: data ➔ split files ➔ compare groups]. Descriptive statistics and frequencies were performed for all the variables/ factors after splitting data to compare the demographics of the patients prescribed a PELVA versus those who were not prescribed a PELVA. The 'prescribed a PELVA' group may contain patients who were also prescribed other aids, and we could not filter out patients who were not prescribed any low vision aids, because the data set did not include information about types of low vision aids that were prescribed, or if patients who were not prescribed a Compact+ were prescribed other aids.

The significance of proportion differences between those prescribed a PELVA and those who were not prescribed one was analysed using Chi-squared test. The significance of variable/ factor differences between the two groups (prescribed versus not prescribed a PELVA) were analysed using non-parametric tests, Mann-Whitney U (2 samples), because the data were not normally distributed [SPSS: analyse ➔ nonparametric tests ➔ independent samples and analyse ➔ nonparametric tests ➔ legacy dialogs ➔ 2 independent samples].

Graphs and charts were created using either SPSS 20 or Excel 2013, where appropriate.

In order to predict which factor(s) affected PELVAs prescribing, multiple regression analysis was carried out [SPSS: analyse ➔ regression ➔ linear ➔ dependent variable (prescribed a PELVA) ➔ independents (all variables/factors in the data set) ➔ estimates, model fit, descriptive, confidence interval (95%)].

Adults and children analysis:

Children have different requirements than adults. Therefore, the data set was also analysed for adults (> 18 years) and for children (=< 18 years).

5.3. Results

A total of 6,668 patient records were included in the analysis. Data (age, gender, living situation, registration of visual impairment, ocular conditions, binocular Log MAR distance visual acuity, and prescribed a Compact+) were not normally distributed (Kolmogorov-Smirnov, $p < 0.001$). Also, the normal Q-Q plot of prescribing was not normally distributed; data points stray from the line in a non-linear fashion.

5.3.1. Summary of the total data set

Of the 6,668 patient records assessed, the median age of the patients was 83 years (interquartile range 76-88) (Figure 5.1), of whom, 65.7% (4384) were female. The median binocular distance visual acuity of patients was 0.60 Log MAR (interquartile range 0.40-1.00) (Figure 5.2). Counting fingers was not recorded in the service data set. A visual acuity of 2.00 Log MAR is equivalent to one letter seen at a distance of 0.5 metre, i.e. 1.98 which was approximated to 2.00 Log MAR in the service data set (Figure 5.2). Sixty six patients had a distance visual acuity worse than 2.00 Log MAR, i.e. Hand Movements (44), Light Perception (16), and No Light Perception (6). Patients were diagnosed with different ocular conditions, some patients having more than one ocular condition (the principle cause of visual impairment was not specified in the data set). The demographics of patients are shown in Table 5.1 which includes the findings for: 1) all patients, 2) adults (> 18 years), and 3) children (=< 18 years).

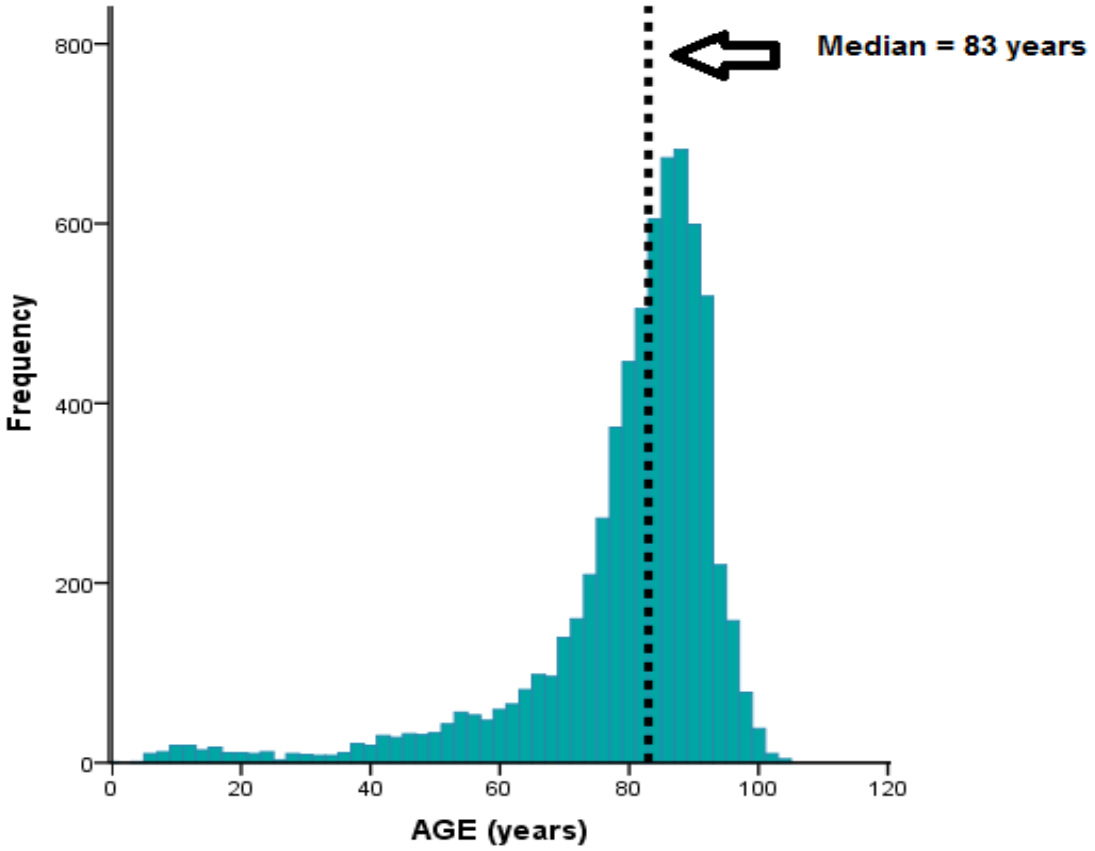


Figure 5.1: The age distribution of 6,668 patients (median 83 years) assessed in the LVSW in 2011/2012.

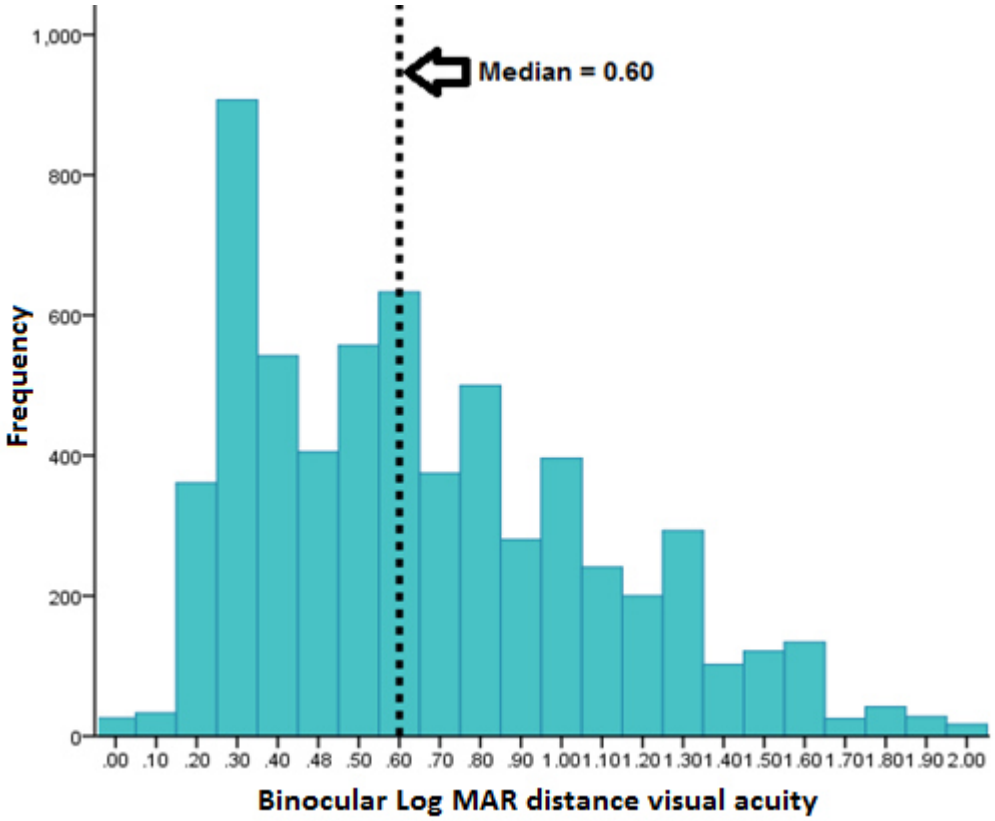


Figure 5.2: The Binocular Log MAR distance visual acuity of the study group (n=6,668) (median 0.60, interquartile range 0.40 – 1.00). Sixty six patients had a distance visual acuity worse than 2.00 Log MAR distance visual acuity (Hand Movements, Light Perception, and No Light Perception) and hence are not included in this histogram. Counting fingers was not recorded in the service data set. A visual acuity of 2.00 Log MAR is equivalent to one letter seen at a distance of 0.5 metre i.e. 1.98 which was approximated to 2.00 Log MAR in the service data set.

Characteristic	Category	All patients (i.e. including adults and children) n=6,668	Adults (i.e. aged > 18 years) n=6,564	Children (i.e. aged = < 18 years only) n=104
Age (Years)		Median (83.37) Range (0-104) IQR (76-88)	Median (84) Range (19-104) IQR (76-88)	Median (11) Range (0-18) IQR (9-15)
Gender	Female	4,384 (65.7%)	4,331(66%)	53 (51%)
	Male	2,282 (34.2%)	2,231(34%)	51 (49%)
Visit Type	Assessment	6,310 (94.6%)	6,214(94.7%)	96 (92.3%)
	Follow up	358 (5.4%)	350(5.3%)	8 (7.7%)
Eye Conditions	AMD Total	4,246 (63.7%)	4,246(64.7%)	0
	AMD Wet	1,167 (17.5%)	1,167(17.8%)	0
	AMD Dry	3,508 (52.6%)	3,508(53.4%)	0
	AMD Not Specified	64 (1.0%)	64(1.0%)	0
	Diabetic Eye Disease	462 (6.9%)	462(7.0%)	0
	Cataract	1,962 (29.4%)	1,958(29.8%)	4 (3.8%)
	Nystagmus	138 (2.1%)	93(1.4%)	45 (43.3%)
	Glaucoma	869 (13.0%)	867(13.2%)	2 (1.9%)
	Other Eye Conditions	1,109 (16.6%)	1,052(16.1%)	55 (52.9%)
	Diagnosis Not Known	68 (1.0%)	66 (1.0%)	2 (1.9%)
	Missing	358 (5.4%)	350 (5.3%)	8 (7.7%)
Binocular Log MAR distance visual acuity		Median (0.60) Range (0.00- NLP†) IQR (0.40-1.00)	Median (0.60) Range (0.00-NLP†) IQR (0.40-1.00)	Median (0.50) Range (0.00- NLP†) IQR (0.30-0.80)
Living Situation	Alone	2,782 (41.7%)	2,782 (42.4%)	NE
	With Partner/ Spouse	2,222 (33.3%)	2,215(33.7%)	NE
	With other People	720 (10.8%)	641(9.8%)	NE
	Sheltered Accommodation	237 (3.6%)	237(3.6%)	NE
	Residential Care	182 (2.7%)	182(2.8%)	NE
	Other	28 (0.4%)	26(0.4%)	NE
	Missing	497 (7.5%)	481 (7.3%)	16 (15.4%)
Registration of Visual Impairment	Sight impaired	1,221 (18.3%)	1,184(18.0%)	37 (35.6%)
	Severely Sight Impaired	799 (12.0%)	793(12.1%)	6 (5.8%)
	Not Registered	3,256 (48.8%)	3,229(49.2%)	27 (26%)
	Not Known	200 (3.0%)	192(2.9%)	34 (32.7%)
	Missing	1,192 (17.9%)	1,164 (17.7%)	0
Prescription of Compact+	Prescribed	664 (10.0%)	626 (9.5%)	38 (36.5%)
	Not Prescribed	6,004 (90.0%)	5,938 (90.5%)	66 (63.5%)

Table 5.1: The demographics of all patients (n= 6,668), adults aged > 18 years (n = 6,564), and children aged =< 18 years (n = 104) who attended the LVSW during the year 2011/2012. AMD= Age-related Macular Degeneration. Statistics includes number and (percentage) of the total number included, except where indicated as median, range, and interquartile range (IQR). [Patients may have multiple ocular conditions (e.g. Wet and dry AMD; cataract and glaucoma; AMD and nystagmus)]. † No light perception (NLP). NE = not evaluated; the analysis of children living situation was not appropriate because in the LVSW the record cards are designed for adults, and there is not an option 'living with family/ parents'.

5.3.2. The prescribing patterns for a PELVA in the LVSW in the year 2011/2012

Of the 6,668 patients, 10% (664) of all patients were prescribed a PELVA (Compact+). This was similar to the percentage of adults who were prescribed a PELVA (9.5%). A summary of the demographics of patients who were prescribed a PELVA compared to those who were not prescribed a PELVA is shown in Table 5.2.

Those who were prescribed a PELVA were:

1) **Younger:** The median age of patients who were prescribed a PELVA was 77 years compared to 84 years of those who were not prescribed (Mann Whitney U, $p < 0.001$) (Table 5.2, Figures 5.3 and 5.4). These were similar to the age of adults who were prescribed a PELVA (median 78 years) and to the age of adults who were not prescribed a PELVA (median 84) (Table 5.2, Figure 5.4).

		All patients (n=6,668)			Adults (n=6,564)			Children (n= 104)		
		Prescribed a PELVA (n=664)	Not prescribed a PELVA (n=6004)	P-value	Prescribed a PELVA (n=626)	Not prescribed a PELVA (n=5938)	P-value	Prescribed a PELVA (n=38)	Not prescribed a PELVA (n=66)	P-value
Visit type	**Assessment**	556 (83.7%)	5,563 (92.7%)	<0.001*	533 (85.1%)	5,681(95.7%)	<0.001*	33 (86.8%)	63 (95.5%)	<0.001*
	Follow up	108 (16.3%)	440 (7.3%)		93 (14.9%)	257(4.3%)		5 (13.2%)	3 (4.5%)	
Gender	**Female**	380 (57.2%)	4,004 (66.7%)	<0.001*	361(57.7%)	3,970(66.9%)	<0.001*	19 (50%)	34 (51.5%)	0.845
	Male	284 (42.8%)	1,998 (33.3%)		265(42.3%)	1,966(33.1%)		19 (50%)	32 (48.5%)	
Age[1] (Years)	**Median**	77	84	<0.001**	78	84	<0.001**	12	11	0.316
	Range	5-102	0-104		19-102	19-104		5-18	0-18	
	IQR	58-85	77-89		63-86	77-89		9-15	9-14	
Binocular Log MAR distance visual acuity	**Median**	0.90	0.60	<0.001**	0.90	0.60	<0.001**	0.50	0.50	0.290
	Range	0.1- NPL†	0.00- NPL†		0.1.00-NPL†	0.00-NPL†		0.20-1.60	0.00-NPL†	
	IQR	0.60-1.20	0.40-0.90		0.60-1.30	0.40-0.90		0.48-0.80	0.30-0.80	
Eye conditions[2]	**AMD not specified**	5 (0.8%)	59 (1%)	0.745	5(0.8%)	59(1%)	0.826	0	0	-
	AMD WET	128 (19.3%)	1,039 (17.3%)	0.008*	128(20.4%)	1,039(17.5%)	<0.001*	0	0	-
	AMD DRY	226(34%)	3,282 (54.7%	<0.001*	226(36.1%)	3,282(55.3%)	<0.001*	0	0	-
	Total AMD	315 (47.4%)	3,931 (65.5%)	<0.001*	315(50.3%)	3,931(66.2%)	<0.001*	0	0	-
	Diabetic eye disease	60 (9%)	402 (6.7%)	0.002*	60(9.6%)	402(6.8%)	<0.001*	0	0	-
	Cataract	100 (15.1%)	1,862 (31%)	<0.001*	98(15.7%)	1,860(31.3%)	<0.001*	2 (5.3%)	2 (3%)	<0.001*
	Nystagmus	40 (6%)	98 (1.6%)	<0.001*	22(3.5%)	71(1.2%)	<0.001*	18 (47.4%)	27 (40.9%)	0.540
	Glaucoma	72 (10.8%)	797 (13.3%)	0.447	71(11.3%)	796(13.4%)	0.660	1 (2.6%)	1 (1.5%)	<0.001*
	Other eye conditions	162(24.4%)	947(15.8%)	<0.001*	145(23.2%)	909(15.3%)	<0.001*	17 (44.7%)	38 (57.6%)	0.154
Living situation	**Alone**	196(29.5%)	2,586(43.1%)	<0.001*	196(31.3%)	2,586(43.6%)	<0.001*	NE	NE	-
	With partner/ spouse	269(40.5%)	1,953(32.5%)	<0.001*	265(42.3%)	1,950(32.8%)	<0.001*	NE	NE	-
	With other people	70(10.5%)	650(10.8%)	0.052	44(7.0%)	597(10.1%)	0.071	NE	NE	-
	Sheltered Accommodation	13(2%)	224(3.7%)	<0.001*	13(2.1%)	224(3.8%)	<0.001*	NE	NE	-
	Residential care	4(0.6%)	178(3%)	<0.001*	4(0.6%)	178(3%)	<0.001*	NE	NE	-
	Other	2(0.3%)	26(0.4%)	0.060	2(0.3%)	24(0.4%)	0.062	NE	NE	-
	Not known	110(16.6%)	387(6.4%)	<0.001*	102(16.4%)	374(6.3%)	<0.001*	NE	NE	-
Registration	**Sight impaired**	181 (27.3%)	1,040(17.3%)	<0.001*	166(26.5%)	1,018(17.1%)	<0.001*	15 (39.5%)	22 (33.3%)	<0.001*
	Severely sight impaired	176(26.5%)	623(10.4%)	<0.001*	173(27.6%)	620(10.4%)	<0.001*	3 (7.9%)	3 (4.5%)	<0.001*
	Not registered	140(21.1%)	3,116(51.9%)	<0.001*	130(20.8%)	3,099(52.2%)	<0.001*	10 (26.3%)	17 (25.8%)	0.621
	Not known	167(25.2%)	1225 (20.4%)	0.421	144(23%)	1,201(20.3%)	0.590	10 (26.3%)	24 (36.4%)	<0.001*

Table 5.2: The demographics of patients who were prescribed a PELVA versus those that were not prescribed one. IQR = interquartile range. * P-value significant (Chi squared, p < 0.05) ** P-value is significant (Mann-Whitney test, p < 0.05). [1]0 the age is < 1 year. [2]Some patients had more than one ocular condition, therefore the sum of percentages of eye conditions is more than 100%. †No light perception (NLP). NE = not evaluated; the analysis of children living situation was not appropriate because in the LVSW the record cards are designed for adults, and there is not an option 'living with family/ parents'.

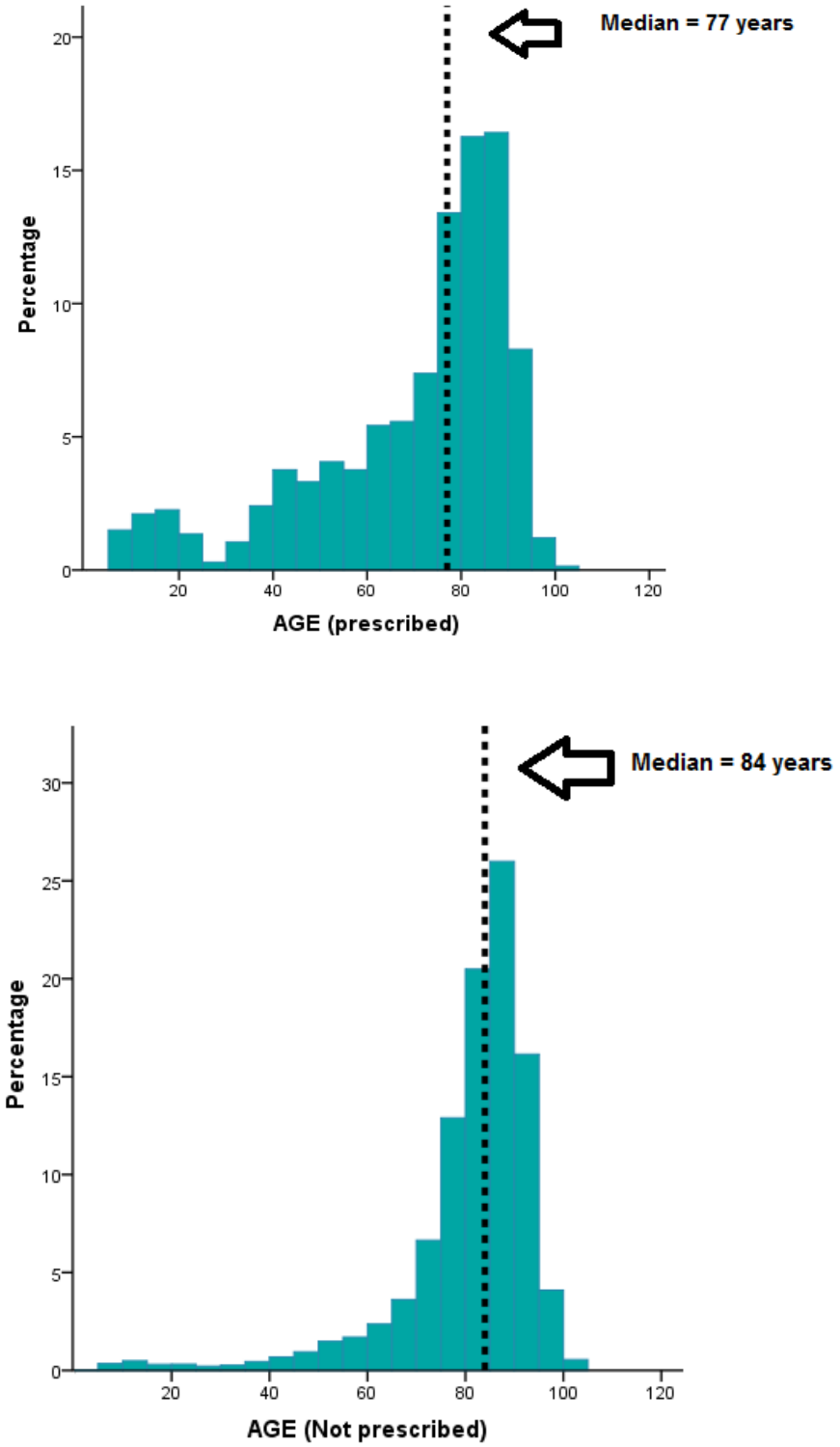
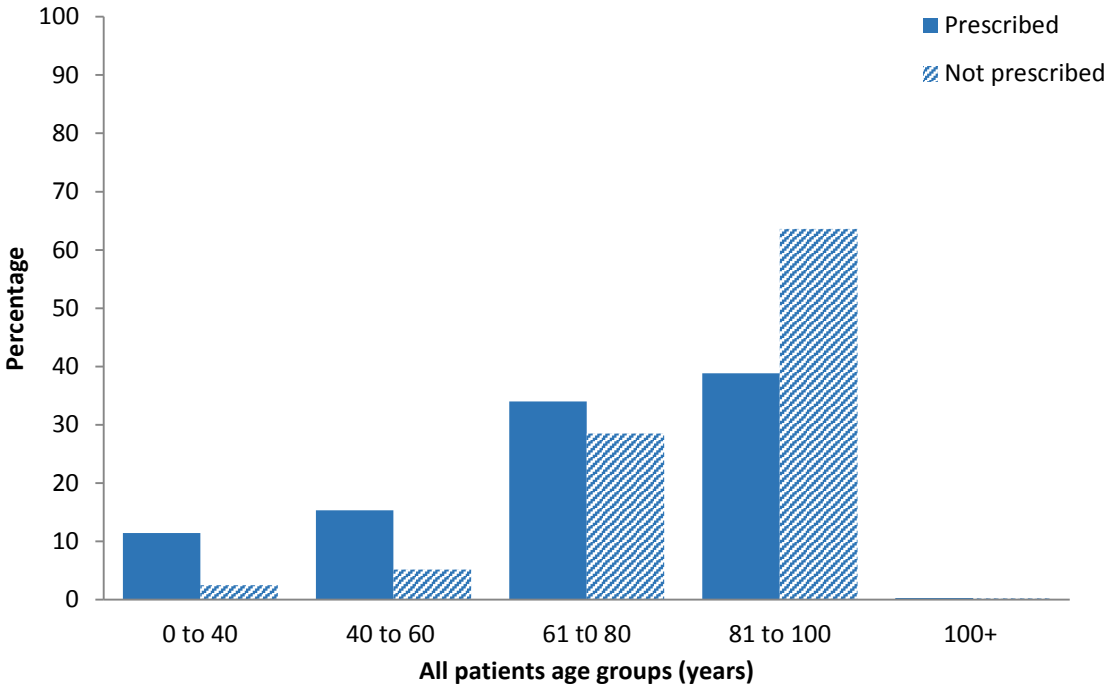


Figure 5.3: The age distribution of all patients who were prescribed a PELVA (n=664) [median age = 77 years] and those who were not prescribed (n=6004) [median age = 84 years].



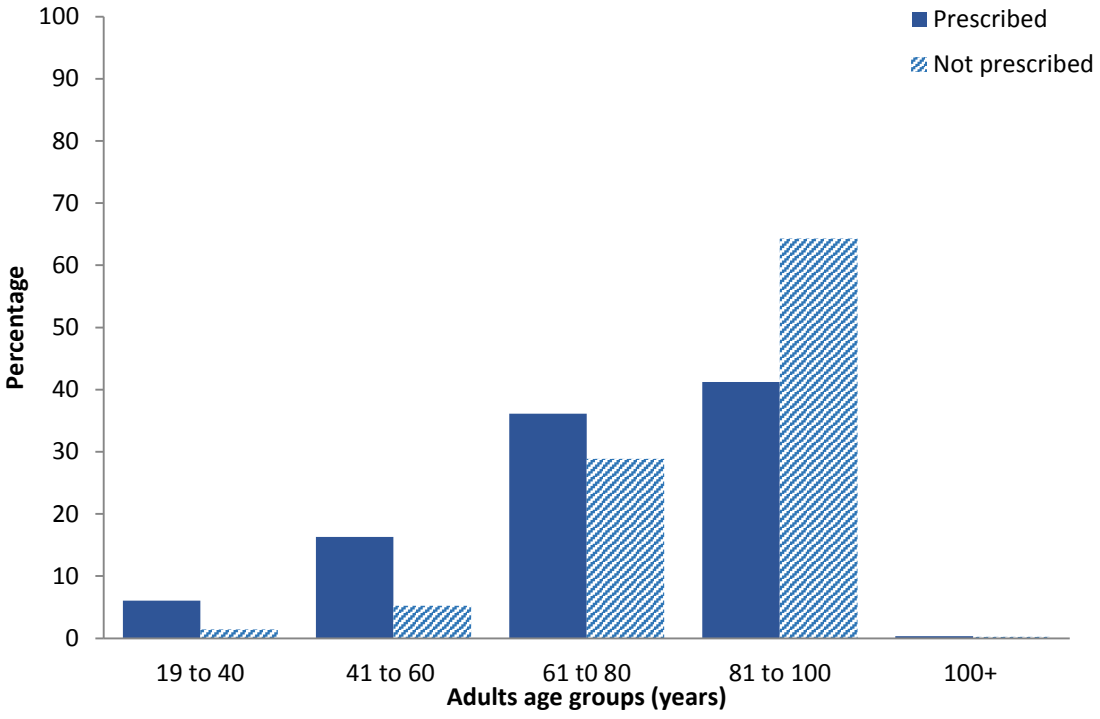


Figure 5.4: A comparison between percentages of patients who were prescribed a PELVA and those who were not prescribed by age group. All patients who were prescribed PELVA were younger (median 77 years) than those who were not prescribed (median 84 years), this was not different for adult patients.

2) **More likely to be "male":** Although there were more females [65.8% (4,384)] compared to males [34.2% (2,282)] in the data set (n=6,668), males were more likely to be prescribed a PELVA; 12.4% (284 out of 2,282) of males in the sample were prescribed a PELVA, compared to 8.7% (380 out of 4,384) females (Chi squared, $p < 0.05$). There were 42.8% (284) males out of 664 patients who were prescribed a PELVA compared to 33.3% (1,998) males out of 6,004 of those not prescribed (Table 5.2, Figure 5.5). On the other hand, 57.2% (380) females out of 664 patients were prescribed a PELVA compared to 66.7% (4,004) females out of 6,004 of those not prescribed (Table 5.2, Figure 5.5) (Chi squared, $p < 0.001$). The exclusion of children aged 18 years or younger did not significantly affect these results; 42.3% (265) out of 626 adults who were prescribed a PELVA were males compared to 33.1% (1,966) out of 5,938 adults who were not prescribed (Table 5.2).

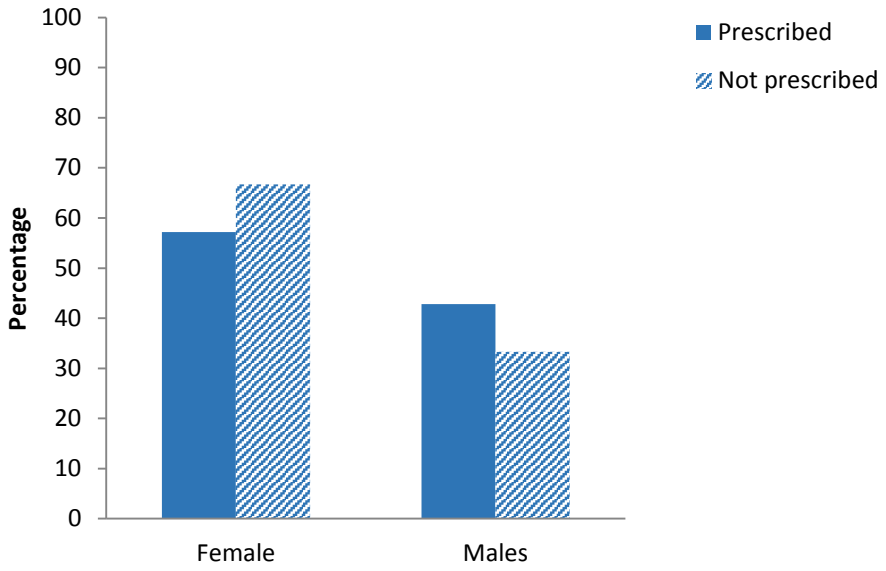


Figure 5.5: Percentage of all patients (n=6,668) who were prescribed a PELVA (n=664) compared to those who were not prescribed (n=6,004) by gender.

3) **More likely to live with "a partner/ spouse" and less likely to live "alone", in "a residential care" or in "a sheltered accommodation"):** There were 40.5% (269) out of 664 patients who were prescribed a PELVA compared to 32.5% (1,953) out of 6,004 not prescribed live "with a partner or a spouse" (Chi squared, $p < 0.001$) (Table 5.2, Figure 5.6). While out of 6,004 who were not prescribed a PELVA, there were 43.1% (2,586) live "alone", 3% (178) live in "a residential care", and 3.7% (224) live in "a sheltered accommodation" compared to 29.5% (196) live alone, 0.6% (4) live in residential care, and 2% (13) live in sheltered accommodation of those who prescribed a PELVA (Chi squared, $p < 0.05$) (Table 5.2, Figure 5.6). Exclusion of children aged 18 years or younger did not significantly affect the results (Table 5.2).

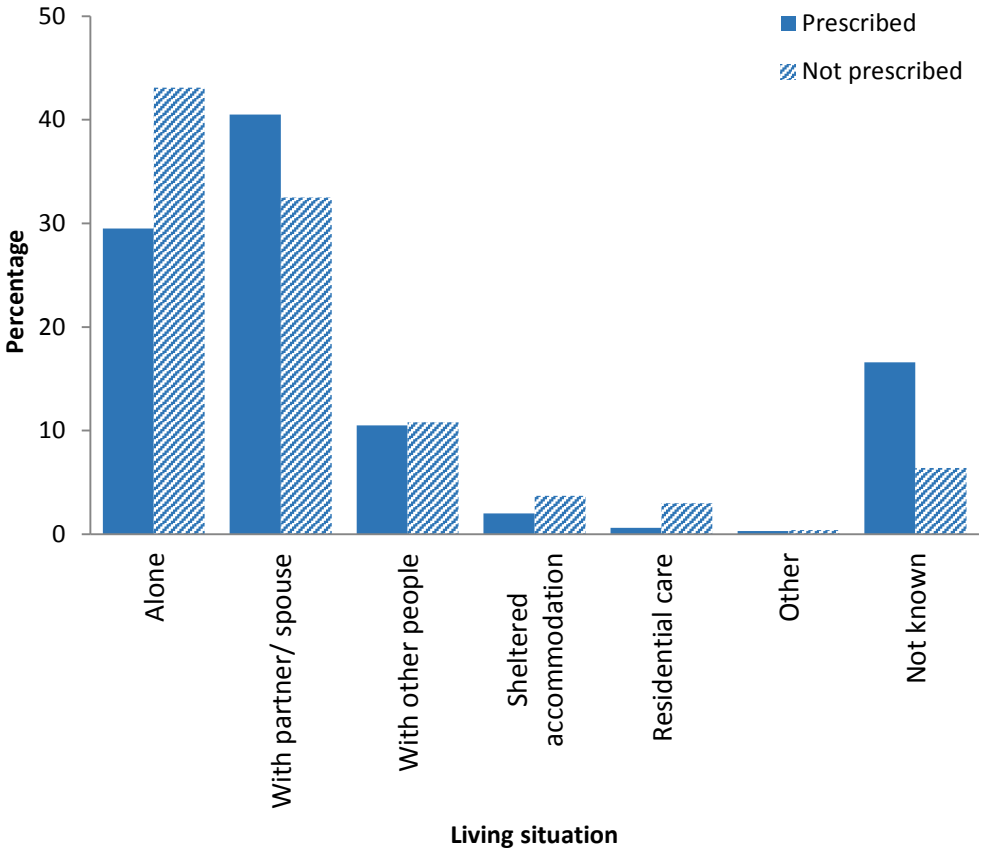


Figure 5.6: The living situation of all patients who were prescribed a PELVA (n=664) and those who were not prescribed (n=6004).

4) **More likely to have poorer visual acuity:** Visual acuity was not normally distributed (Kolmogorov Smirnov, $p < 0.05$). Median distance Log MAR visual acuity for those who were prescribed a PELVA was 0.90 compared to 0.60 for patients who were not prescribed (Mann Whitney U, $p < 0.001$) (Table 5.2, and Figures 5.7 A and B). The exclusion of children aged 18 years or younger did not affect the results (Table 5.2).

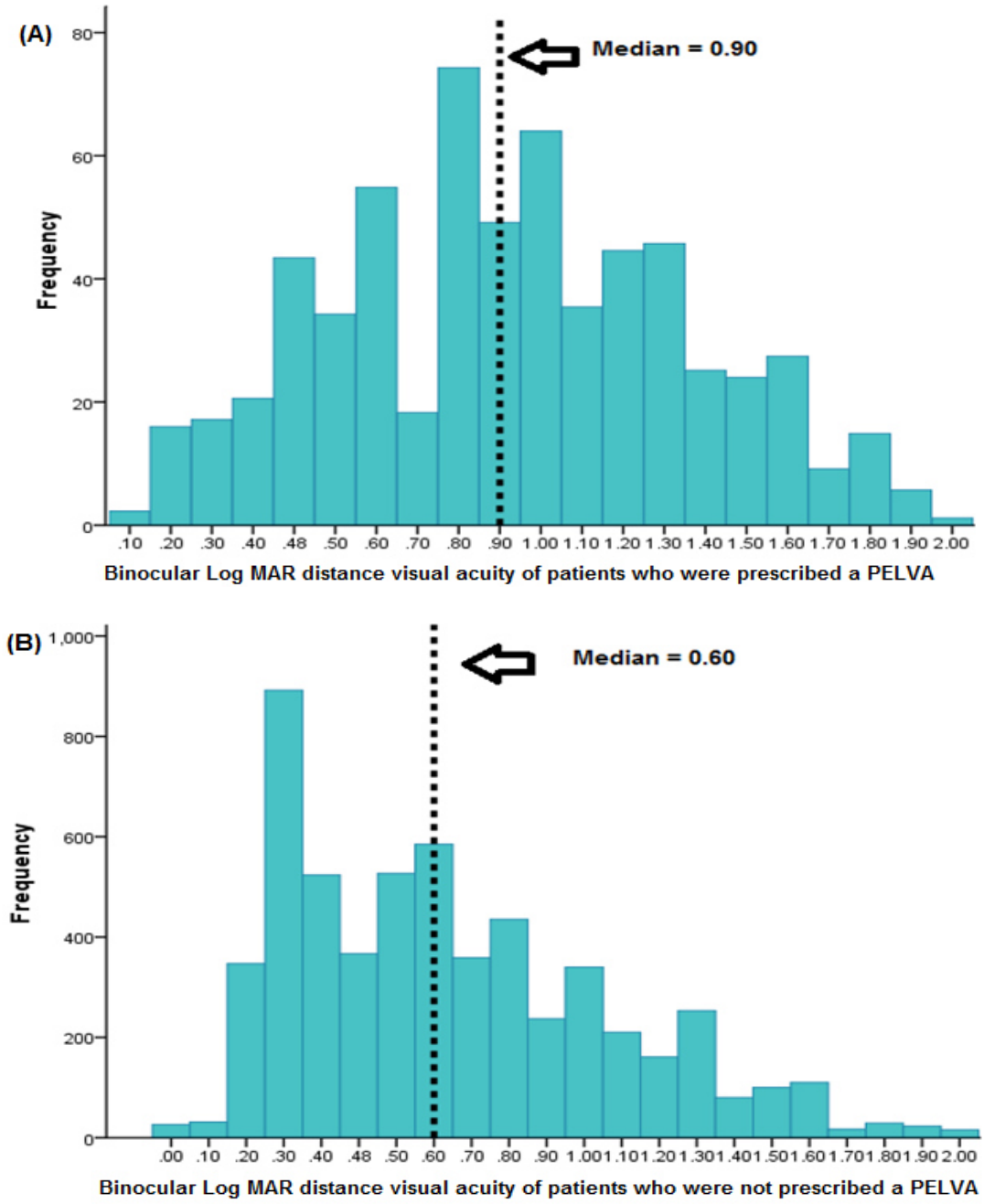


Figure 5.7: (A) Visual acuity of all patients who were prescribed a PELVA (median 0.90). The 13 patients that had a visual acuity worse than 2.00 Log MAR visual acuity are not included in this histogram (Hand Movements 9, Light perception 3, and No Light Perception 1). (B) Visual acuity of patients who were not prescribed a PELVA (Median 0.60). The 53 patients that had a visual acuity worse than 2.00 Log MAR visual acuity are not included in this histogram (Hand movements 35, Light Perception 13, and No Light Perception 5). Counting fingers was not recorded in the service data set. A visual acuity of 2.00 Log MAR is equivalent to one letter seen at a distance of 0.5 metre i.e. 1.98 which was approximated to 2.00 Log MAR in the service data set.

5) More likely to be registered as "sight Impaired" or 'severely sight impaired':

Patients who were prescribed a PELVA [n=664] were more likely to be registered as "sight impaired" 27.3% (181), and "severely sight impaired" 26.5% (176) compared to 17.3% (1,040) "sight impaired" and 10.4% (623) "severely sight impaired" of those who were not prescribed (Chi squared, $p < 0.001$) (Figure 5.8 and Table 5.2). A total of 21.1% (140) of those prescribed a PELVA [n=664] were "not registered", and 25.2% (167) did not know if they were registered or not (Figure 5.8 and Table 5.2). Registration of visual impairment was self-reported; it was not confirmed by social services or hospital records. The exclusion of children aged 18 years or younger did not significantly affect these results (Table 5.2).

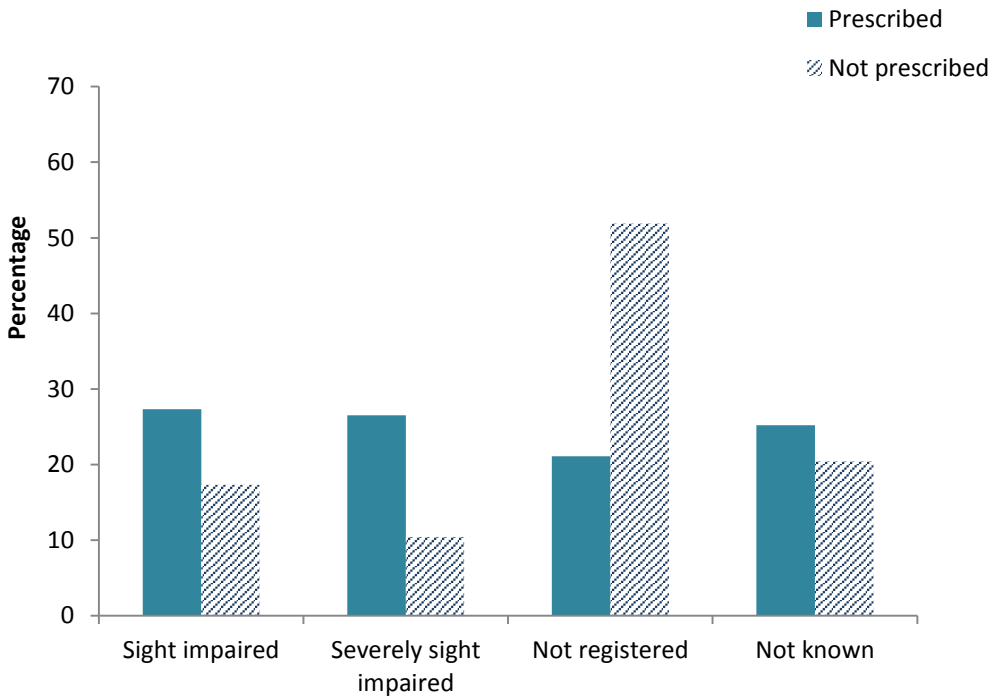


Figure 5.8: The registration of visual impairment status of patients who were prescribed a PELVA (n=664) and those who were not prescribed (n=6,004).

6) Were diagnosed with different ocular conditions:

The sum of percentages of all ocular conditions exceeded 100% (160.8%), because some patients had multiple ocular conditions (e.g. cataract and glaucoma; AMD and nystagmus).

i) **Age related macular degeneration (AMD):** Out of 664 patients who were prescribed a PELVA, 47.4% (315) had AMD (including wet AMD, dry AMD, and not specified AMD) whereas out of the 6,004 patients who were not prescribed a PELVA 65.5% (3,931) had AMD (Chi squared, $p < 0.001$). Therefore patients who were prescribed a PELVA were less likely to have AMD.

Patients who were prescribed a PELVA were more likely to have wet AMD 19.3% (128) [n=664] compared to 17.3% (1039) [n= 6,004] of those not prescribed (Chi squared, $p = 0.008$). Patients who were prescribed a PELVA were less likely to have dry AMD 34% (226) [n=664] compared to 54.7% (3,282) of the 6,004 patients who were not prescribed (Chi squared, $p < 0.001$) (Figure 5.9 and Table 5.2).

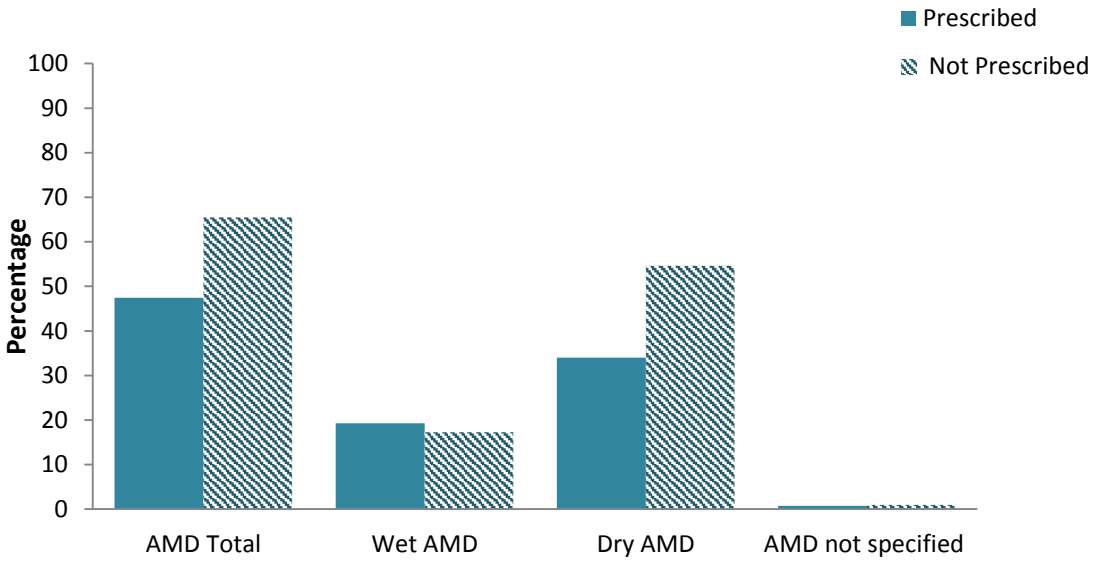


Figure 5.9: The percentage of all patients with age-related macular degeneration (Wet, Dry, Not specified, and Total) for those who were prescribed a PELVA (n=664) and those not prescribed (n=6,004).

ii) **Cataract:** Patients who were prescribed a PELVA were less likely to have cataract; 15.1% (100) of 664 patients who were prescribed a PELVA had cataract compared to 31% (1,862) of the 6,004 who were not prescribed (Chi squared, $p < 0.001$) (Figure 5.10 and Table 5.2).

iii) **Glaucoma:** There was no significant difference in the prevalence of glaucoma between patients who were, and those who were not, prescribed a PELVA; 10.8% (72) [n=664] and patients who were not prescribed 13.3% (797) [n=6,004] (Chi squared, $p = 0.447$) (Figure 5.10 and Table 5.2).

iv) **Diabetic eye disease:** Patients who were prescribed a PELVA were more likely to have diabetic eye disease; 9% (60) [n=664] compared to those who were not prescribed 6.7% (402) [n=6,004] (Chi squared, p = 0.002) (Figure 5.10 and Table 5.2).

v) **Nystagmus:** Patients who were prescribed a PELVA were more likely to have nystagmus; 6% (40) [n=664] compared to those not prescribed 1.6% (98) [n=6,004] (Chi squared, p < 0.001) (Figure 5.10 and Table 5.2).

vi) **Other eye conditions:** There were 24.4% (162) [n=664] of patients prescribed a PELVA who had other eye conditions/ disorders such as retinitis pigmentosa, optic nerve atrophy, cystoid macular oedema etc., compared to 15.8% (947) [n=6,004] of those not prescribed a PELVA (Chi squared, p < 0.001) (Figure 5.10 and Table 5.2).

The distribution of ocular disorders for patients who were prescribed a PELVA compared to those not prescribed is shown in Figure 5.10 and Table 5.2. The exclusion of children aged 18 years or younger did not significantly affect these results (Table 5.2).

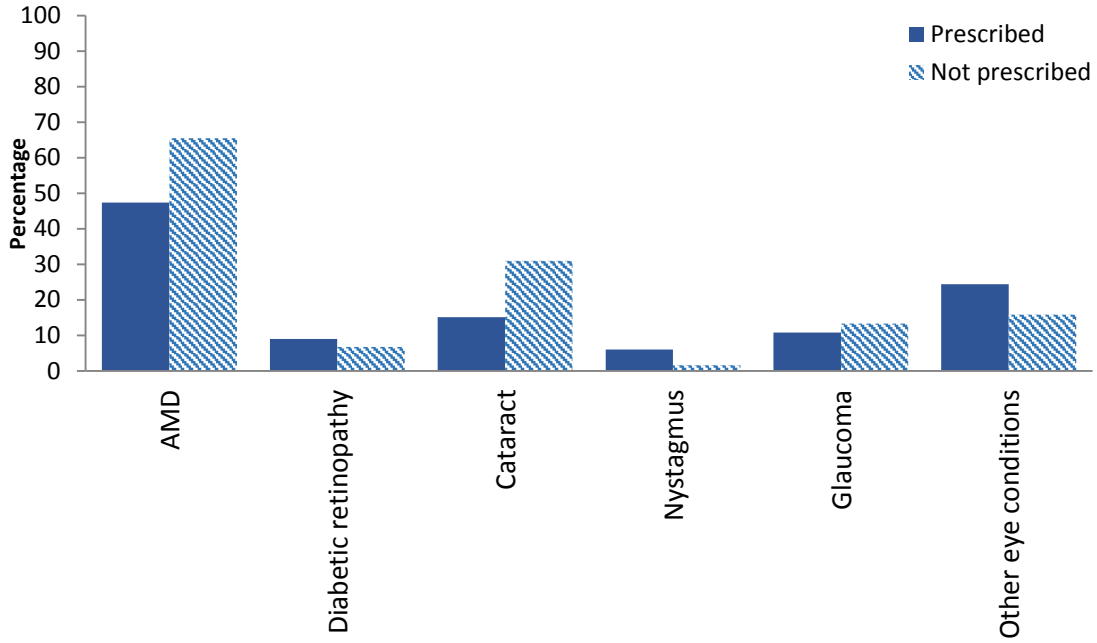


Figure 5.10: Ocular conditions for all patients who were prescribed a PELVA (n=664), and all patients who were not prescribed (n=6,004).

Overall, there was a lower proportion of patients who had multiple ocular conditions of those prescribed a PELVA compared to those not prescribed. There were 36.6% (242) out of 664 patients who were prescribed a PELVA who had multiple ocular conditions compared to 52.5% (3,152) out of 6,004 who were not prescribed (Chi squared, $p < 0.001$).

There was no significant difference in the distribution of multiple ocular conditions at each category (e.g. one ocular condition, two ocular conditions) between patients who were prescribed a PELVA and those not. Out of 664 patients who were prescribed a PELVA, 58% (395) had only one ocular condition (e.g. AMD only, cataract only, etc.) compared to 50.3% (3,022) out of 6,004 who were not prescribed (Chi squared, $p > 0.05$).

35% (117) out of 664 who were prescribed a PELVA had two ocular conditions compared to 32% (1,924) of those not prescribed (n=6,004) (Chi squared, $p > 0.05$). 6.6% (36) of those prescribed (n=664) had three ocular conditions compared to 5.8% (349) of patients who were not prescribed (n=6,004) (Chi squared, $p > 0.05$). Also, 0.5% (3) of those prescribed (n=664) had four ocular conditions and 0.5% (30) (n=6,004) of those not prescribed (Chi squared, $p > 0.05$).

5.3.3. Factors affecting prescribing for PELVAs for patients with visual impairment

In the sample (n=6,668), there were more 'older patients'. There was also twice as many females as males. Females live longer and are more likely to have visual impairment. Also, younger patients are more likely to live with a partner or a spouse. This may have affected other attributes. For example, older people are more likely to live alone.

Therefore, multiple linear regression analysis was performed for. This showed that for:

All patients:

About 10% of the total variability in the prescribing for PELVAs for all patients included in this study (n=6,668) was explained by: age, gender, status of visual impairment registration, living situation, distance Log MAR visual acuity, and ocular conditions (including AMD, wet AMD, dry AMD, cataract, glaucoma, diabetic eye disease, and nystagmus) (adjusted R-square = 0.100, $p < 0.001$).

Living situation, having glaucoma, having nystagmus, having diabetic eye disease, having not specified AMD, having dry AMD, having wet AMD, and having other eye conditions (each factor alone holding other factors constant) had no significant relationship with the prescribing of PELVAs (B-coefficient, $p > 0.05$), i.e. they had no predictive ability for patients being prescribed a PELVA (Table 5.3).

Age, gender, distance Log MAR visual acuity, AMD, cataract, and status of visual impairment registration (each factor alone holding other factors constant) had a significant relationship with the prescribing PELVAs (B-coefficient, $p < 0.05$), i.e. had a predictive ability for a patient being prescribed a PELVA or being not prescribed a PELVA (Table 5.3).

Multiple linear regression analysis (Table 5.3) showed that the probability of a patient being prescribed a PELVA was: 1) increased by reducing age by a factor (i.e. B-Coefficient) of 0.004, although there were more older patients in the sample [median age 83.37, OR = 3.079], 2) increased by being a male by a factor of 0.02, although there were twice as many females as males in the total sample [Female (65.7% (4,384)), Male (34.2% (2,282)) n=6,668, OR = 1.498], 3) increased by reduction in binocular distance visual acuity (i.e. worse vision) by a factor of 0.090, 4) decreased by having AMD by a factor of 0.04, 5) decreased by having cataract by a factor of 0.018, and 6) decreased by being not registered for visual impairment status by a factor of 0.037, $p < 0.05$ for all of the above cases (Table 5.3).

Factor	All patients (adjusted R square= 0.100 , p < 0.001, constant[1] 0.377)		Adults (adjusted R square= 0.090 , p < 0.001, constant[1] 0.369)		Children (adjusted R square= 0.003 , p = 0.430, constant[1] -1.155)	
	B-coefficient	**p-value**	**B-coefficient**	**p-value**	**B-coefficient**	**p-value**
Age (Years)	-0.004	<0.001*	-0.004	<0.001*	+0.021	0.234
Gender	+0.02	0.017*	+0.018	0.026*	+0.083	0.496
AMD Total	-0.04	0.035*	-0.04	0.035*	--	--
AMD Wet	+0.018	0.209	+0.019	0.192	--	--
AMD Dry	-0.023	0.203	-0.022	0.199	--	--
AMD Not Specified	-0.014	0.745	-0.014	0.743	--	--
Diabetic Eye Disease	+0.004	0.810	+0.006	0.690	--	--
Cataract	-0.018	0.034*	-0.018	0.034*	+0.133	0.611
Nystagmus	+0.034	0.250	+0.008	0.811	+0.058	0.703
Glaucoma	+0.007	0.544	+0.006	0.578	+0.622	0.229
Other Eye Conditions	+0.006	0.614	+0.010	0.403	-0.143	0.347
Binocular Log MAR distance visual acuity	+0.09	<0.001*	+0.088	<0.001*	+0.369	0.077
Living Situation	+0.003	0.123	+0.003	0.107	NE	--
Registration of Visual Impairment	-0.037	<0.001*	-0.039	<0.001*	+0.097	0.260

Table 5.3: Factors affecting the prescribing for PELVAs for 'all patients', adults (> 18 years), and children (=< 18 years). Regression analysis was used to analyse data. * p-value is significant (p < 0.05). [1] Constant is the probability of a patient being prescribed a PELVA when all factors/ predictors (X) equal zero. The prescribing for PELVAs increases (+) or decreases (-) by *B-coefficient, for example the probability of a patient being prescribed a PELVA is increased by reducing age by a factor of 0.004 (B-coefficient = -0.004). -- Not calculated as no patients had this condition. NE = not evaluated; the analysis of children living situation was not appropriate because in the LVSW the record cards are designed for adults, and there is not an option 'living with family/ parents'.

Patients who were prescribed a PELVA were younger. There were 1.6% (104 out 6,668) patients aged 18 years or younger in the data set. Of the 10% (664 out of 6,668) patients who were prescribed a PELVA, there were 5.7% (38 of 664) children (aged 18 years or younger), and 94.3% (626 of 664) patients aged more than 18 years. Although the number of children was small, the data set excluding children aged 18 years or younger was analysed in order to find whether that affected the results.

The characteristics of patients excluding children (i.e. adults) are shown in Table 5.1. The characteristics of adults who were prescribed a PELVA compared to those who were not prescribed are shown in Table 5.2.

Adults:

About 9% of the total variability in the prescribing of PELVAs for adults was explained by: age, gender, status of visual impairment registration, living situation, distance Log MAR visual acuity, and ocular conditions (including AMD, wet AMD, dry AMD, cataract, glaucoma, diabetic eye disease, and nystagmus) (adjusted R-square = 0.090, $p < 0.001$).

Excluding children aged 18 years or younger, the probability of an adult patient being prescribed a PELVA was: 1) increased by reducing age by a factor of 0.004, 2) increased by being a male by a factor of 0.018, 3) increased by reduction in binocular distance visual acuity by a factor of 0.088, 4) decreased by having AMD by a factor of 0.04, 5) decreased by having cataract by a factor of 0.018, and 6) decreased by being not registered for visual impairment status by a factor of 0.039, $p < 0.05$ for all of the above

factors (Table 5.3). Therefore, the exclusion of children from the data set did not affect our conclusion.

Children aged 18 years or younger:

A higher proportion of children (36.5%) were prescribed a PELVA compared to adults (10%) (Chi-squared, $p < 0.05$). Children who were prescribed a PELVA were more likely to have cataract, glaucoma or other eye conditions such as cortical visual impairment and optic atrophy, and more likely to be registered as sight impaired or severely sight impaired. There were no significant differences in age and gender between children who were prescribed a PELVA and children who were not prescribed. The characteristics of children who were prescribed a PELVA compared to those who were not prescribed are shown in Table 5.2.

Multiple regression analysis showed that: age, gender, binocular Log MAR distance visual acuity, eye conditions (AMD, cataract, diabetic eye disease, glaucoma, nystagmus, and other eye conditions), and registration of visual impairment were not predictors for a child being prescribed a PELVA (adjusted R-square = 0.003, $p = 0.430$). B-coefficient, $p > 0.05$ for each of the above factors (Table 5.3).

5.4. Discussion

In this study, despite PELVAs being available on loan free of charge at the LVSW, only 10% (664) [n=6,668] patients were prescribed these devices. Patients who were prescribed a PELVA were significantly younger, more likely to be males, (although there were twice as many females as males in the data set), were more likely to live with a partner/ spouse, less likely to live alone or in a sheltered accommodation or in a residential care, had poorer visual acuity, more likely to be registered as sight impaired or severely sight impaired, were less likely to have AMD, less likely to have cataract, more likely to have diabetic eye disease, more likely to have nystagmus, and more likely to have other eye conditions compared to those not prescribed.

The tendency to present PELVAs to younger males may be because males and younger people tend to use technology such as computers, tablets and smartphone more than females and older people. In 2013, 37% of people aged 65 and older used computers compared to (80 to 88%) of people aged less than 50 years (Office for National Statistics, 2013). Smith and Necessary (1996) reported that compared to females, males had more positive attitudes towards using technology or computers (Office for National Statistics, 2013). There were 9% of UK household females used tablet computers compared to 13% of UK households' males (Ofcom Communications Market Report, 2012). Therefore, optometrists might be less likely to offer PELVAs to older patients and women, or it may be that older patients and women were more likely to turn them down.

An internal document (Ryan, 2011) outlined the 'prescribing patterns' for Compact+ (a PELVA) in the LVSW. She evaluated data set of about 4,300 low vision patients. The author reported that 12.25% (527) of patients were prescribed Compact+. This was slightly different to findings of this study where 10% (664) out of 6,668 patients with visual impairment were prescribed. This slight drop may be because there were more patients interested in PELVAs initially. She also found that patients who were prescribed Compact+ tended to be younger, male, and had poorer visual acuity, similar to the findings of this study. From experience in low vision practice, she suggested that prescribing Compact+ might be a suitable choice for patients with poor visual acuity (0.6 Log MAR or worse). The findings are similar to this study in which patients who were prescribed a PELVA had poorer visual acuity (median binocular distance Log MAR visual acuity 0.90, interquartile range 0.60-1.20).

Results from the Lighthouse National Survey on Vision Loss (1995) show that of study populations aged 45 years and older, 30% of patients with self-reported visual impairment used optical visual aids such as magnifiers or telescopes, whereas large print texts were used by 21% of patients, and about 5% used adaptive visual aids such as talking books and clocks. It was not clear if electronic low vision aids were included in the study (Lighthouse National Survey on vision loss 1995, Jutai et al. 2005).

Crossland and Silver (2005) studied the change in the prescribing patterns for low vision aids over 30 years at Moorfields Eye Hospital. They found that younger patients (aged

60 years or less) tended to be prescribed more than one low vision aid. Also, there was a linear increase in the number of prescribed hand magnifiers, bright field magnifiers, and illuminated hand magnifiers but a decline in the number of prescribed spectacle-mounted telescopes with age. Their study did not include electronic low vision aids because they were not available for prescribing (only for demonstration). The authors explained that the decline in the number of prescribed spectacle-mounted telescopes could be explained by the increased availability of electronic low vision aids such as CCTVs, and the development of illuminated hand magnifiers besides the high cost of spectacle-mounted telescopes.

From experience in low vision practice Ryan (2011) suggested that PELVAs may provide patients with more fluent reading as they have a wider field of view compared to optical magnifiers. The author also suggested that Compact+ might be useful for patients with low contrast sensitivity (Ryan, 2011). Although we did not have contrast sensitivity data, this was not consistent with our finding, that patients who were prescribed a PELVA were less likely to have cataract. This might be because of age; among those who had cataract, the median age of patients who were prescribed a PELVA was 81 years compared to 85 years of those not prescribed. The median age of 'all patients' who had cataract in our study was 84 years this is older than the median age of patients who were prescribed a PELVA (77 years). Also, information about the type and classification of cataract and if one eye or both eyes were affected was not included in patients records. Culham et al. (2004) found that contrast sensitivity of patients with visual impairment using CCTVs was not better than that using optical low vision aids. In

Chapter 4 of this thesis, luminance contrast was significantly improved for low contrast and high contrast texts using some PELVAs. This is an area that requires further investigation and in particular looking at whether patients with reduced contrast sensitivity are more likely to be prescribed a PELVA.

Patients who were prescribed a PELVA had poorer visual acuity. This may be because PELVAs can be more useful for patients with severe reduction of vision. Li et al. (2002) found that of 203 patients with visual impairment who attended Chang Gung Memorial Hospital, 86.6% had improved their reading with optical low vision aids and 5.1% with CCTVs (Li et al., 2002). Those who benefited from using CCTVs had poorer visual acuity compared to those benefited from using optical low vision aids (Li et al., 2002). The authors suggested that when optical low vision aids fail to improve vision of some patients, electronic low vision aids may be useful (Li et al., 2002). Nguyen et al. (2009) found that although 42% of low vision patients show improvement in reading speed using CCTVs, patients with severe visual impairment (< 20/200) experienced significantly lower improvement in reading speed compared to patients with better visual acuity (>= 20/200) (Nguyen et al., 2009). Culham et al. (2004) found that younger patients and those with better distance visual acuity experienced more improvement in reading small print using electronic low vision aids compared to optical low vision aids, and younger age was a predictor of faster reading speed (Culham et al., 2004). The authors found that the near visual acuity and contrast sensitivity of those using electronic low vision aids were the same as for those using optical low vision aids. Flipperport and Jordy (electronic head-mounted devices) significantly increased distance and intermediate

visual acuities compared to optical low vision aids (Culham et al., 2004). Optical low vision aids were more useful for the majority of visual tasks compared to electronic low vision aids (Culham et al., 2004). Patients with visual acuity of better than 1.2 Log MAR gained little benefit from using electronic vision enhancement systems, and many had a higher reading speed using optical low vision aids (Fonda et a. 1975, Jackson and Wolffsohn 2007). Compared to adults, young people were highly motivated to use electronic vision enhancement systems, but they were less likely to use them regularly (Fonda et al. 1975, Zabel et al. 1982, Jackson and Wolffsohn 2007). However, Watson et al. (1997) reported that age and visual acuity were not related to the continued use of electronic vision enhancement systems.

Goodrich and Kirby (2001) found that reading speed and reading duration were significantly better using CCTVs compared to optical low vision aids in patients with central field loss (Goodrich and Kirby, 2001). This might be because larger CCTVs have a bigger screen which provides a larger field of view.

Nguyen et al. (2009) reported that out of 530 patients (age 83±8 years) which is almost similar to our study population (median age 83.4 years, interquartile range 76-88) with AMD (different stages), visual rehabilitation was achieved mostly using optical low vision aids 58% (307) [n=530] and less by electronic low vision aids (CCTV) 42% (223) [n=530]. This is far higher than our study findings' in which only 10% were prescribed a PELVA. The Nguyen et al. study represents the prescribing pattern from a private practice in the US. Also, this might be explained by the fact that the average distance visual acuity of

their study population was worse (0.80 Log MAR equivalent) than our study population (median = 0.60 Log MAR equivalent). Our study found that patients with poorer distance visual acuity were more likely to be prescribed a PELVA.

Although patients who were prescribed a PELVA were more likely to live with a partner or a spouse, more likely to have nystagmus and diabetic eye disease they were not predictors for a patient being prescribed a PELVA. There were only a few factors found, using multiple linear regression analysis, that can be considered predictors for a patient being prescribed a PELVA. These include: being younger, being male, a reduction in binocular visual acuity, not having AMD, not having cataract, and being registered for visual impairment.

Patients who live with a partner or a spouse, although living arrangement was not a predictor for prescribing a PELVA, were more likely to be prescribed a PELVA in this study. This might be because patients who were prescribed a PELVA, and live with a partner, have poorer binocular distance Log MAR visual acuity (median 0.90) than those who were not prescribed and live with a partner (median 0.60). Also, the use of a new device could be more convenient if a patient had someone to assist with the use of low vision aids at home.

Patients who were prescribed a PELVA were more likely to have diabetic retinopathy and nystagmus, although neither were predictors for PELVAs prescribing. This might be explained by the fact that patients who were prescribed a PELVA and had diabetic eye

disease were younger in this sample (median age 66 years) compared to those who were not prescribed but had diabetic eye disease (median age 74 years). The median age of patients who had diabetic eye disease in this study was 73 years. Similarly, patients who were prescribed a PELVA and had nystagmus were younger (median age 34.50 years) compared to those who were not prescribed but had nystagmus median age (42.5 years). The median age of patients who had nystagmus in this study was 41.50 years.

Patients who were prescribed a PELVA were less likely to have AMD although two thirds of the study sample had AMD. AMD is more prevalent in females compared males (RNIB, 2015). In this study, about 70% of those had AMD were females compared to 30% males. The median age of patients who had AMD in this study was 86 years (interquartile range 81-89) this is older than the median age of patients who were prescribed a PELVA.

There were twice as many females in this data set and according to RNIB statistics two third of patients with visual impairment are women (RNIB, 2015). Certain diseases such as AMD and cataract affect older people particularly women, and women live longer than men.

Of the children aged 18 years or younger (n=104), 36.5% (38) were prescribed a PELVA. Children who were prescribed a PELVA were more likely to have cataract, glaucoma or other eye conditions such as cortical visual impairment and optic atrophy, and more likely to be registered as sight impaired or severely sight impaired. However, age, gender, binocular Log MAR distance visual acuity, eye conditions, and status of visual

impairment registration were not predictors ($p > 0.05$) of PELVAs prescribing among children aged 18 years or younger. This suggested that the prescribing patterns for PELVAs was different compared to adults, and other factors such as children preference or device ergonomics might affected PELVAs prescribing for children.

In the LVSW, the record cards are designed for adults, and there is not an option 'living with family/ parents', so some practitioner may tick 'living with a partner/ a spouse' to mean relatives. Therefore, the analysis of children living situation was not appropriate in this study particularly that children do not live alone or in sheltered accommodation or residential care.

Overall, the larger proportion of children aged 18 years and younger (36.5%) compared to adults (10%) were prescribed a PELVA might be explained by the fact that younger are more likely to use technology such as computers and tablet computers such as iPads (Office for National Statistics 2013, Anderson and Rainie 2012), or because ergonomics of PELVAs might draw less attention to children which might make more preference towards PELVAs, or possibly because they might have less fear of using technology. Nickson (2015) reported that children felt perfectly comfortable with new technology and they did not have fear about pushing buttons and trying new technology compared to older people.

Excluding children aged 18 years or younger (104 of 6,668), did not affect the results in this study. This is likely to be because there were a small number of children in the data set.

Our study was important, because it is the first to describe the prescribing patterns for electronic low vision aids, the sample was also large. This will help those planning low vision services. It was difficult to develop a model for prescribing of PELVAs from the data set in this study, however we found a group of significant predictors for a patient to be prescribed a PELVA including age and gender.

This study did not provide information about the tasks for which patients were prescribed a PELVA and if patients who were not prescribed a PELVA had more cognitive or physical limitations. Also, it was not clear what low vision aids other than (PELVAs) were prescribed. Moreover, it did not include an assessment of visual functions such as contrast and reading performance (with and without a PELVA) for patients who were prescribed a PELVA. However, each patient should be considered on an individual basis and factors such as patient's expectations, and preferences should be considered. The fact that there was no restriction on prescribing and yet only 10% of patients were prescribed a PELVA provides a holistic view of the need for these devices in NHS services.

Although the number of children in the data set is small (n=104) and it is not representative of children with visual impairment, the fact that 36.5% of children were prescribed a PELVA suggests that PELVAs should be of considered for children.

There is evidence of deterioration of rehabilitation effect over time; the effect at two months was higher than at six months (Kuyk et al., 2008) and the effect at three months was higher than at 12 months (Stelmack et al., 2007).This study cannot conclude if patients still continue to use PELVAs. How many patients stopped using PELVAs? How do they rate them? What they are using them for? What things they think would improve these devices? Whether they use any other devices along with PELVAs? In the next chapter, patients' self-reported satisfaction of PELVAs compared to optical magnifiers will be explored further.

5.5. Conclusion

Despite Compact+ (a PELVA) being available for prescription for patients with visual impairment on loan free of charge, only 10% of patients attending the LVSW were prescribed these devices.

Predictors (significant factors) for a patient being prescribed a PELVA include: younger age, being a male, poorer visual acuity, being registered as sight impaired or severely sight impaired, not having AMD or cataract. This will be useful for those planning services to consider the need in their patient base.

Compared to adults, a higher proportion of children aged eighteen years and younger 36.5% were prescribed a PELVA. Children who were prescribed a PELVA were more likely to have cataract, glaucoma or other eye conditions such as cortical visual impairment and optic nerve atrophy, and more likely to be registered as sight impaired or severely sight impaired. Device ergonomics or preference might affect PELVAs prescription among children.

Other factors that could affect PELVAs prescribing such as patients rating and satisfaction, improvement of visual function (for example, contrast and reading performance), and low vision aid parameters (for example, field of view), devices ergonomics should be explored further.

CHAPTER 6: The use and self-reported satisfaction of pocket and portable electronic low vision aids, and optical low vision aids for patients with a visual impairment

6.1. Introduction

It is important to evaluate the outcomes of different low vision aids, to measure how much these devices are used and meet the needs or the aims of patients with a visual impairment, and to analyse benefits and limitations of these aids.

The effectiveness of low vision aids for patients with visual impairment can be evaluated based on: 1) assessment of visual functions (visual acuity, contrast sensitivity, reading speed and comprehension) (Hiatt et al. 1963, Nilsson and Nilsson 1986, Rosenthal and Cole 1991, Whittaker and Lovie-Kitchin 1993, Leat et al. 1994, Harper et al. 1999, Margrain 2000, Culham et al. 2009, Markowitz et al. 2012), 2) assessment of quality of life reported by patients, aspects including mobility, orientation, functional status, mental status, self-care, social status (Hinds et al. 2003, Reeves et al. 2004, De-Boer et al. 2006, Lamoureux et al. 2007, Binns et al. 2012), 3) assessment of psychological status (Engel et al. 2000, Horowitz et al. 2005, Horowitz et al. 2006), 4) assessment of self-reported ability to perform daily living tasks (i.e. functional ability) (Haymes et al. 2001, Pankow et al. 2004, Eklund et al. 2008, Binns et al. 2012).

Functional ability measures can be rated depending on the patients assessment of their functional ability, this approach can be called a 'self-reported' or patient rated assessment. Questionnaires that employ this approach include the Veterans Affairs LV

VFQ-48 (Stelmack et al. 2006, Stelmack et al. 2007), National Eye Institute Visual Function Questionnaire NEI VFQ-25 (Mangione et al. 2001, Stelmack et al. 2002, La-Grow 2004, Kuyk et al. 2008), NEI-VFQ 51 (Scott et al., 1999), the Manchester Low Vision Questionnaire (MLVQ) (Harper et al. 1999, Hinds et al. 2003), and 5) assessment of frequency and use of low vision aids (either at follow up or at variable periods of time) (Van-Rens et al. 1991, McIlwaine et al. 1991, Shuttleworth et al. 1995).

Although clinical assessment of visual functions is very important, it does not necessarily reflects patients' satisfaction. Because assessment of visual functions is usually performed in a clinic setting, it may not reflect patients' capabilities at home. Leat et al. (1994) found that 75% of patients show good near visual acuity when it was measured in a clinical setting, but only 39% were able to read small print size at home. There may be a need for new outcome measures that could evaluate the outcome of provided services based on the quality of life assessment rather than clinical assessment. On the other hand, McKnight and Babcock-Parziale (2007) found that there was no significant difference between clinical rated and self-rated scores using the Functional Assessment of Self Reliance in Tasks (FAST).

Hiatt et al. (1963), Virtanen and Laatikainen (1991), and Margrain (2000) assessed the improvement of visual functions such as reading ability of a newspaper print using the low vision aids, and found that the use of the low vision aids improved reading ability in 90% of patients.

Nilsson and Nilsson (1986) found that the provision of distance and near low vision aids for patients who had diabetic retinopathy improved their distance visual acuity from 0.78 to 0.14 Log MAR equivalent, and near visual acuity from N20.8 to N4.2. Telescopes were the most frequent distance low vision aids used with average magnification of 4.8X, and near addition and hyperocular lenses were the most frequent near low vision aids used with average magnification of 5.6X.

Nilsson and Nilsson (1986) found that there was an improvement in both distance (from 0.76 to 0.20 Log MAR equivalent) and near visual acuity (from N20.9 to N4.9) of patients with age related macular degeneration after the provision of distance and near low vision aids. Telescopes were the most frequent distance low vision aids used with average magnification of 4.6X, and near addition and hyperocular lenses were the most frequent near low vision aids used with average magnification of 5.7X.

Goodrich et al. (2006) found that there was a significant improvement in reading speed after the prescription of optical or electrical low vision aids with training sessions.

McCabe et al. (2000) found an improvement of 50% in clinical functional outcomes using the Functional Visual Performance Test (FVPT), and 10% in self-reported functional abilities using the Functional Assessment Test (FAQ) after the provision of a comprehensive rehabilitation program (training and low vision aids).

Hinds et al. (2003) used an interview-based questionnaire (MLVQ) to follow up patients 6 months after attending an interdisciplinary low vision service. They found that patients used their low vision aids to accomplish different reading tasks such as reading instructions, and reading newspapers. They also found that 75% of patients who were prescribed low vision aids used or attempted to use them for reading ordinary print books, and 72% described low vision aids as extremely or moderately helpful (Hinds et al., 2003). Reeves et al. (2004) used the MLVQ to follow up patients one year after the provision of a comprehensive rehabilitation program and found similar results.

Crossland et al. (2007) analysed the response of 15 patients, by using open interview, before and after three months of the provision of magnifiers, and found that 40% of patients had experienced improvement in their quality of life.

Scott et al. (1999) carried out telephone interviews, 3 months after the provision of low vision rehabilitation and found that 90% of patients rated the low vision service as helpful.

Stelmack et al. (2006) and Stelmack et al. (2007) found a significant improvement in the performance of daily living activities (ADLs), 3 months and 12 months after the provision of an intensive Veterans Affairs rehabilitation program, using the VA LV VFQ-48.

Nilsson and Nilsson (1986) found that about 90% of patients who had diabetic retinopathy and discontinue their work because of visual impairment, return to work after the provision of low vision aids.

Haymes et al. (2001) reported that there was a significant improvement in ADLs performance, after 1 week of the provision of a multidisciplinary rehabilitation program for 22 patients with visual impairment. The authors assessed the improvement of ADLs performance using the Melbourne Low Vision ADL Index (MLVAI).

Pankow et al. (2004) found that the provision of a home based rehabilitation program, for 15 patients with visual impairment, significantly improved their functional abilities measured by using the Functional Independence Measure for Blind Adults (FIMBA), a clinical rated tool.

De-Boer et al. (2006) found that, after the provision of a rehabilitation program, there was a small but significant improvement in vision related quality of life (including depression, safety, fear of vision deterioration, and anger) using the Vision Quality of Life Core Measure (VCM1), but no significant improvement was found using the Low Vision Quality of Life Questionnaire (LVQOL). Hinds et al. (2003) found that, 6 months after the provision of a rehabilitation program, there was a slight improvement in vision related quality of life using the VCM1.

Wolffsohn and Cochrane (2000) found a significant improvement in vision related quality of life, 1 month after the provision of a multidisciplinary rehabilitation program for 278 patients, assessed using the LVQOL tool. The authors reported that reading and fine work were the most improved compared to general vision, mobility, and ADLs.

Kuyk et al. (2008) found a significant improvement in vision related quality of life using the NEI-VFQ 25, after 2 and 6 months of intervention. Stelmack et al. (2002) found moderate improvement in vision related quality of life, after the provision of an intensive Veterans Affairs rehabilitation program using the NEI-VFQ 25. On the contrary, La-Grow (2004) found that there was no significant improvement of vision related quality of life, 6 months and 1 year after the provision of comprehensive and standard low vision services; assessed using the NEI-VFQ 25.

To date, there has been limited literature available on the effectiveness of electronic low vision aids particularly PELVAs (Goodrich et al. 1977, Harper et al. 1999, Goodrich and Kirby 2001, Li et al. 2002, Peterson et al. 2003, Culham et al. 2009, Virgili and Acosta 2009, Dyment 2009).

The aim of this study was to evaluate self-reported assessment of PELVAs compared to optical low vision aids for patients with visual impairment who attended the LVSW in the year 2011-2012, using the Manchester Low Vision Questionnaire (MLVQ). The objectives were to:

1) Evaluate the tasks low vision aids (PELVAs and optical low vision aids) were used for, i.e. the purpose of using low vision aids.
2) Evaluate the usefulness of low vision aids for a group of visual tasks, e.g. reading newspaper print.
3) Evaluate the frequency and duration of reading that was achieved with the low vision aids.
4) Compare PELVAs and optical low vision aids from the patients' perspective in terms of use, rating, and reading frequency and duration.

6.2. Methods

This is a pilot study that evaluated patients' self-reported assessment of PELVAs compared to optical low vision aids for patients with visual impairment who attended the LVSW in the year 2011-2012, using the Manchester Low Vision Questionnaire (MLVQ).

The MLVQ is a validated tool that measures the use of low vision aids. It consists of two parts (a total of 20 short questions) (Harper et al., 1999). The first part evaluates the purpose of using low vision aids for a group of tasks (18 tasks) such as reading newspapers, sewing, knitting, watching TV etc. To evaluate and to rate the usefulness of low vision aids for a specific visual task, a score from 1 to 4 is used (1 = not at all helpful, 2 = slightly helpful, 3 = moderately helpful, 4 = extremely helpful). The second part is more specific for reading tasks and includes 2 questions; the first question evaluates the frequency of reading with low vision aids and the second question evaluates the duration of reading that can be achieved with low vision aids at any one time. Items of the MLVQ are included in Appendix (II). In this study we excluded tasks related to distance vision (watching TV, reading street signs, being on a trip) because we were interested in evaluating the near vision tasks such as reading for which PELVAs are used. We included tasks related to near vision (15), and we used the second part of the MLVQ twice; firstly to evaluate reading frequency and duration using PELVAs, and secondly to evaluate reading frequency and duration using optical low vision aids.

6.2.1. Ethics

All study protocols, invitation letters, patient information sheets, and consent forms were approved by the School of Optometry and Vision Sciences Ethical Committee (Project no. 1351 4th July 2014) (Appendix III). The study was registered at Cardiff and Vale University Health Board as a Service Evaluation (27th June 2013) (Appendix III).

6.2.2. Recruitment

Records for those patients who attended the LVSW in the year 2011/2012 who consented to be contacted for research/ audit purposes were selected at random by the manager of the LVSW. The patients were sent an invitation to participate in this study. A total of 543 invitations were sent (279 invitations for patients who were prescribed a PELVA and 264 for those not prescribed a PELVA) by the LVSW by post. There was more consent received initially from patients who used optical low vision aids. Therefore in order to achieve almost equal number of participants of those who used PELVAs and those who used optical low vision aids, a reminder letter was sent by the LVSW to 159 patients who had PELVAs (100 after 2 months, and 59 after 3 months of sending the initial invitations). Patients who consented to participate in the study were then telephoned in order to arrange a phone interview. Details of patients' invitations and responses are included in the results section in this chapter.

6.2.3. Phone interview

Patients were interviewed by phone using 20 questions/ items (15 near vision tasks, and 1 question about reading frequency using PELVAs, 1 question about reading duration

using PELVAs, 1 question about reading frequency using optical low vision aids, 1 question about reading duration using optical low vision aids, and 1 question about types of low vision aids used by patients) taken from the MLVQ (Figure 6.1). Items/ questions related to distance vision of the original MLVQ were excluded. The original MLVQ is shown in Appendix II.

PARTICIPANT ID/ NAME: ---------- **TIME & DATE:** ----------
CALL DURATION: ---------- **PHONE NUMBER:** ----------

Appointment/ interview:
Good AM/PM, I am …… calling from Cardiff University regarding LVSW service evaluation. We received your response and we appreciate your consent to participate in our study. The study is about evaluating magnifiers. The interview will take about 15 minutes; is this a good time for you or should I call you later?

Outlines of the questionnaire:
Firstly I would like to ask you, what type of magnifiers do you use? Is it an electronic or optical magnifier or do you use both?

Magnifier	Comments
Optical	
Electronic	
Others	

Part I (The use and satisfaction of devices):
This part includes 15 short questions regarding the purpose of use and rating the satisfaction of devices.

PART I. During the last 6 weeks, have you (15 tasks) --- (Task)--- ? (Answer yes/no) If yes:
How helpful you found PELVA/ Optical device? (Answer: Extremely/ Moderately/ Slightly/ or not at all helpful)

	Task	YES PELV	Rating	YES OPTICA	Rating	NONE	Comments
1	Read ordinary print books or newsprint/		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
2	Read large print books, large print		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
3	Read letters/ cards/ bank statements/		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
4	Read your own writing		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
5	Read instructions on packets, tins,		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
6	Read shop prices/ labels/ tickets		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
7	Read the markings on dials—e.g., on the		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
8	Read the telephone directory to check		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
9	Read the time on your watch		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
10	Filled in forms, cheques, cards, etc.		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
11	Signed your own name		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
12	Written your own letters		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
13	Identified money		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
14	Sewed/ knitted/ or mended		1/ 2/ 3/ 4		1/ 2/ 3/ 4		
15	Done a special hobby		1/ 2/ 3/ 4		1/ 2/ 3/ 4		

Part II: How often and how long you use your magnifier for reading?
1. How often do you use your optical magnifier for reading?
Several times a day/ Once each day/ A few times each week/ Once each week/ Rarely/ Never
2. How often do you use your PELVA for reading?
Several times a day/ Once each day/ A few times each week/ Once each week/ Rarely/ Never
3. How long can your optical magnifier be used for reading at any one time?
< 1 min/ 1-5 mins/ 6-10 mins/ 11-30 mins/ > 30 mins
4. How long can your PELVA be used for reading at any one time?
< 1 min/ 1-5 mins/ 6-10 mins/ 11-30 mins/ > 30 mins

**** Personal responses from patients e.g. why they experienced or found this, how this can be improved, etc.?**

Figure 6.1: The interview form, questions taken from the MLVQ (Harper et al., 1999).

6.3. Results

6.3.1. Invitations and response rate

A total of 543 invitations were sent to patients (279 patients who were prescribed a PELVA and 264 patients who were not prescribed a PELVA). There were 113 replies returned; and 19 were unable to participate (2 had passed away, 4 were in hospital, 6 had changed their addresses, 3 had hearing difficulty and could not arrange someone to assist them during the interview, and 4 envelopes were returned with no reply or comments or consent). In total, 94 of 543 (17.3%) patients were recruited to take part in the study. It was not possible to reach 6 of those that initially consented to take part by phone i.e. sample loss of 6 out of 95 (6.4%). Therefore, 88 out of 94 (93.6%) were interviewed (Figure 6.2). This was a pilot study, so there was no sample power calculation.

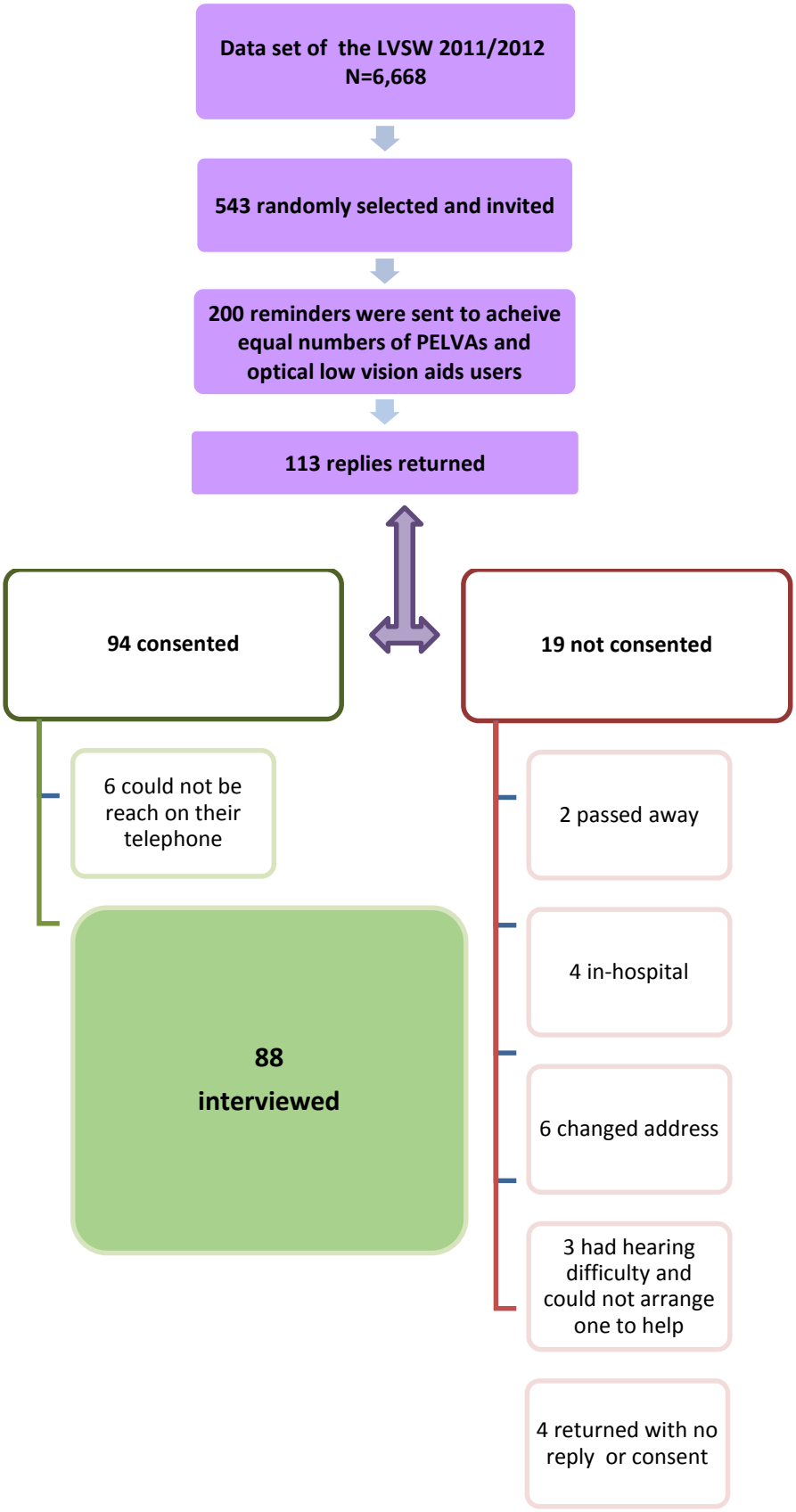


Figure 6.2: Patients recruitment and participation.

6.3.2. Low vision aids used

A total of 88 patients were interviewed. Patients used different types of low vision aids including PELVAs and optical low vision aids. Some patients used more than one low vision aid for example, a PELVA and optical low vision aids.

PELVAs and optical low vision aids:

There were 1) 51.1% (45 of 88) patients used a PELVA, 2) 81.8% (72 of 88) patients used optical low vision aids, and 3) 33% (29 of 88) patients used PELVAs and optical low vision aids. The use of PELVAs and optical low vision aids is shown in Figure 6.3.

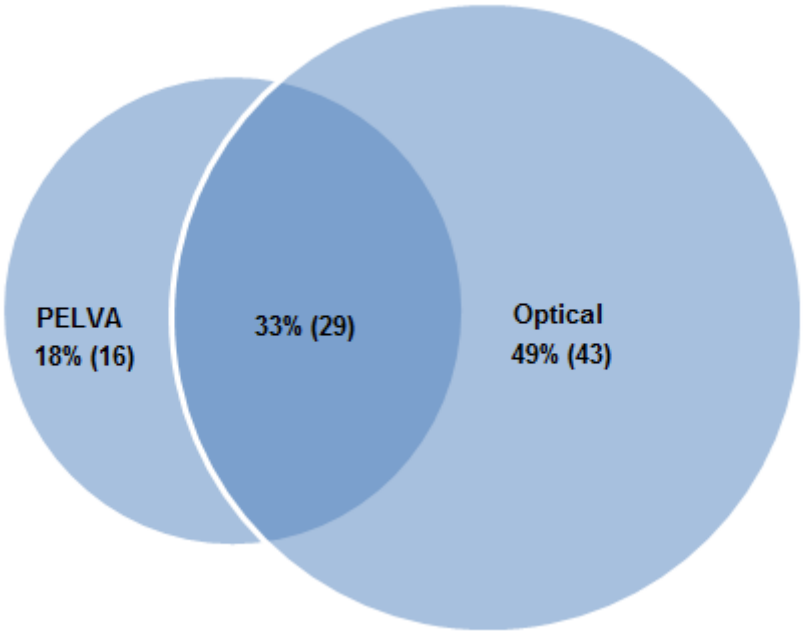


Figure 6.3: The use of PELVA and optical low vision aids, [n= 88]. Some patients used ''other low vision aids'' along with PELVAs and/or optical low vision aids.

Patients who used optical low vision aids (n=72) used a variety of optical low vision aids. These include hand-held magnifiers 87.7% (63), stand magnifiers 27.8% (20), jewellers eye glasses (magnifiers clipped to spectacle lenses, they are used by jewellers and for watch repair and provide up to 20X magnification) 6.9% (5), and spectacle mounted telescopes 2.8% (2). Some patients 23.6% (17) used more than one optical magnifier. The distribution of the optical low vision aids used is shown in Figure 6.4.

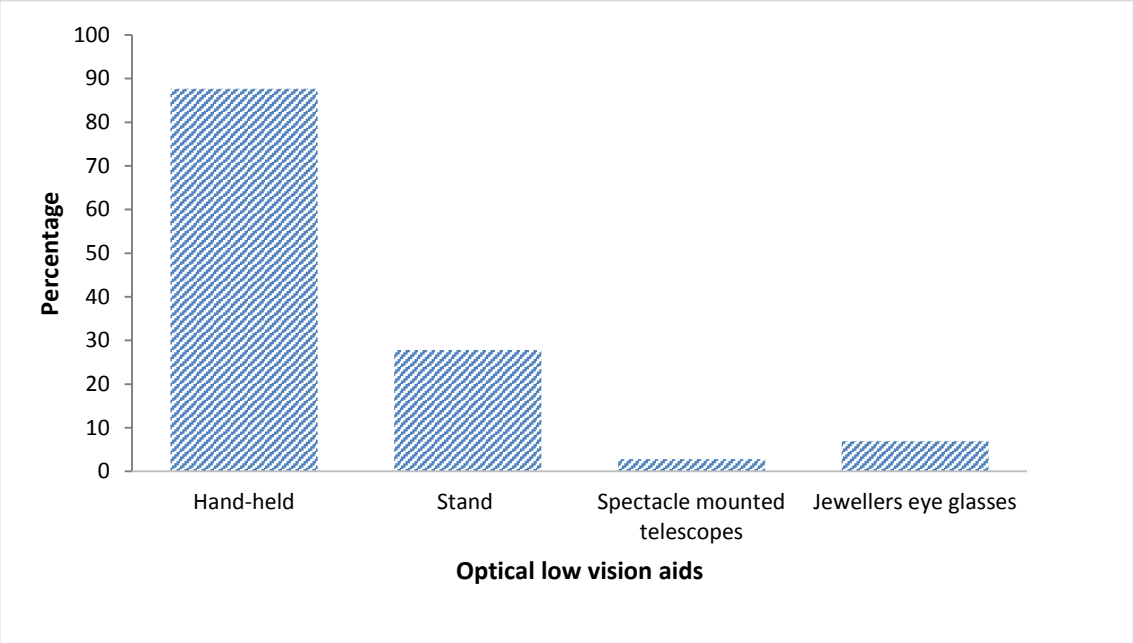


Figure 6.4: The distribution of the use of different types of optical low vision aids used (n=72) (some patients used more than one optical low vision aids e.g. hand-held and stand magnifier).

Other low vision aids (i.e. non-optical, substitution and electronic (excluding PELVAs) low vision aids):

The term 'other low vision aids' refers to non-optical, substitution and electronic (excluding PELVAs) low vision aids. Of the total patients in this study [n=88], 42% (37) used 'other low vision aids': 43% (16) were optical low vision aid users, 19% (7) were PELVAs users, and 38% (14) were PELVAs and optical low vision aids users (Chi squared, $p < 0.001$). The distribution of the use of 'other low vision aids' is shown in Figure 6.5.

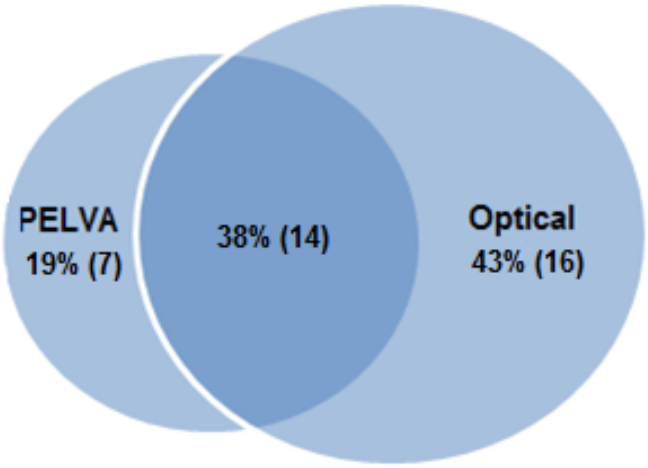


Figure 6.5: The distribution of patients (PELVA users and/ or optical low vision aid users) who used 'other low vision aids' along with PELVA and / or optical low vision aids (n=37).

The use of non-optical devices, sight substitution devices, and electronic low vision aids (excluding PELVAs) is shown in Table 6.1.

Other low vision aids		Percentage (number)
Non-optical devices	Appropriate lighting	10.8% (4)
	Pen	10.8% (4)
	Large print telephone directory	5.4% (2)
	Large print text	2.7% (1)
Sight substitution devices	Talking book	8.1% (3)
	Talking watch	5.4% (2)
Electronic low vision aids (except PELVAs)	CCTV	43.2% (16)
	Computer	16.2% (6)
	Electronic mouse magnifier	8.1% (3)
	Electronic book	5.4% (2)
	E-reader	5.4% (2)

Table 6.1: The distribution of 'other low vision aids' by 37 patients. Some patients used more than one aid/ device.

Patients who used a PELVA also used appropriate lighting and CCTVs. Patients who used optical low vision aids also used appropriate lighting, CCTVs, computers, e-readers, electronic books, large telephone directory, large print text, and talking books. Patients who used both a PELVA and optical low vision aids used also talking watches, computers, CCTVs, an electronic mouse magnifier (an electronic mouse magnifier has a magnifying camera incorporated inside the computer mouse which can be connected to a TV/ monitor), and a pen.

6.3.3. The use and rating of using low vision aids for tasks performed

Fifteen questions from the MLVQ asked about what low vision aids were used for and how helpful they were (rated from 1 to 4: 1= not helpful, 2= slightly helpful, 3= moderately helpful, and 4= extremely helpful). The use and rating of optical low vision aids and PELVAs according to tasks performed are shown in Table 6.2 and Figure 6.6. Overall, it is clear that patients who were prescribed optical low vision aids (n=72) used

them for all of the 15 tasks in this study. Patients who were prescribed PELVAs (n=45) used them for 12 out of the15 tasks. They did not use PELVAs for 'reading the time on their watch', 'writing their own letters', or 'sewing', 'knitting', or 'mending'.

6.3.3.1. Tasks performed using low vision aids (PELVAs compared to optical low vision aids)

Compared to patients who used optical low vision aids, a larger proportion of those who used PELVAs used them to: 1) read shop prices/ labels/ or tickets, 2) read instructions on packets, tins, bottles, or medicines, 3) sign their own name, 4) do a special hobby (Table 6.2). Chi squared test, $p < 0.05$ for each of the above cases.

Compared to patients who used PELVAs, a larger proportion of those who used optical low vision aids used them to: 1) read ordinary print books, newsprint, or magazines, 2) read large print books, large print newspapers, or newspaper headlines, 3) read letters, cards, bank statements, or other correspondence, 4) read time on their watch, 5) fill in forms, cheques, or cards, etc., 6) write their own letters, 7) identify money, 8) read a telephone directory, 9) to read marking on dials, 10) sewing, knitting or mending (Table 6.2). Chi squared test, $p < 0.05$ for each of the above cases.

Task	Frequency of use % (Number) of patients who used them for named tasks)		
	PELVAs (n= 45)	Optical low vision aids (n= 72)	p-value
1. Reading ordinary print books, newsprint, magazines, TV times	37.8% (17)	58.3% (42)	<0.001*
2. Reading large print books, large print newspapers, or newspaper headlines	51.1% (23)	58.3% (42)	<0.001*
3. Reading letters, cards, bank statements/other correspondence	31.1% (14)	58.3% (42)	<0.001*
4. Reading their own writing	6.7% (3)	6.9% (5)	0.871
5. Reading instructions on packets, tins, bottles, medicines, etc	57.8% (26)	48.6% (35)	0.032*
6. Reading shop prices, labels, or tickets	82.2% (37)	37.5% (27)	0.028*
7. Reading markings on dials—eg, on the cooker, radio, hi-fi, washing machine, etc	6.7% (3)	13.9% (10)	<0.001*
8. Reading telephone directory to check numbers	11.1% (5)	25% (18)	<0.001*
9. Reading the time on their watch	0	13.9%	<0.001*
10. Filling in forms, cheques, cards, etc	24.4% (11)	33.3% (24)	0.006*
11. Signing their own name	31.1% (14)	29.2% (21)	0.016*
12. Writting their own letters	0	15.3% (11)	<0.001*
13. Identifying money	22.2% (10)	26.4% (19)	<0.001*
14. Sewing, knitting, or mending	0	9.7% (7)	<0.001*
15. Doing a special hobby	20% (9)	15.3% (11)	<0.001*
* p-value is significant (Chi-squared test, p-value < 0.05)			

Table 6.2: The use of PELVAs (n=45) and optical low vision aids (n=72) for each of the 15 tasks performed.

6.3.3.2. Rating of tasks performed using PELVAs compared to optical low vision aids

Overall, patients who used PELVAs (n=45) described them as extremely helpful for the tasks they used them for; the median for PELVAs rating was 4. Patients who used optical low vision aids (n=72) described them as moderately helpful; the median for optical low vision rating was 3 (Mann Whitney U, $P < 0.001$). Rating of PELVAs compared to optical low vision aids for each individual task is show in Figure 6.6.

PELVAs (n=45) were significantly more helpful than optical low vision aids (n=72) for: 1) reading large print books, large print newspaper or newspaper headlines, 2) reading letters, cards, bank statements, 3) reading shop prices, labels, or tickets, 4) filling in forms, cheques, or cards, 5) signing their own name, 6) identifying money (Figure 6.6). Mann- Whitney U test, $p < 0.001$ for each of the above cases.

Optical low vision aids (n=72) were significantly more helpful than PELVAs (n=45) for: 1) reading ordinary print books, newspapers, or magazines, 2) reading instructions on packets, tins, bottles, medicines, etc., 3) doing a special hobby (Figure 6.6). Mann Whitney U test, $p < 0.001$ for each of the above cases.

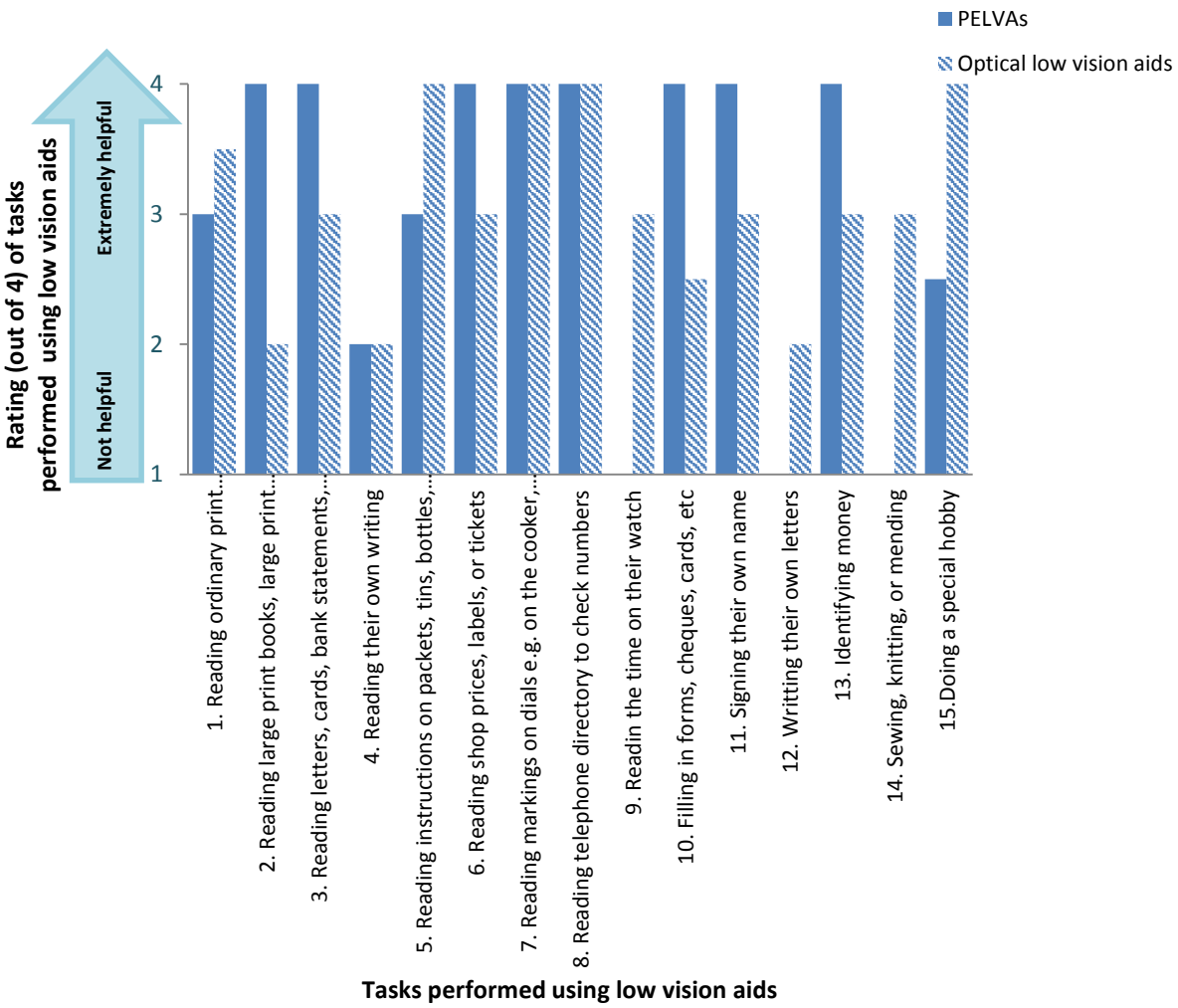


Figure 6.6: Rating of each individual task by patients who used PELVAs (n=45) and patients who used optical low vision aids (n=72) [1= not helpful, 2= slightly helpful, 3= moderately helpful, 4= extremely helpful]. Patients prescribed PELVAs did not use them to 'sew/knit/mend', 'write their own letters' or 'read time on their watch' therefore rating is not shown for PELVA users for these tasks.

There were no significant differences (Mann Whitney U test, $p > 0.05$) between PELVAs and optical low vision aids rating for: 1) reading their own writing, 2) reading marking on dials, 3) reading telephone directory.

6.3.4. Reading frequency using low vision aids

Reading frequency (i.e. how often a patient used PELVAs/or optical low vision aids for reading i.e. Part II of the MLVQ) was evaluated. Optical low vision aids were used significantly more frequently for reading compared to PELVAs (Mann Whitney U, $p < 0.001$). The median frequency of reading using optical low vision aids was 'several times each day' (IQR from 'once each day' to 'several times each day') i.e. patients who used optical low vision aids used them 'several times each day' to read. The median frequency of reading using PELVAs was 'once each day' (IQR from 'few times each week' to 'several times each day') i.e. patients who used PELVAs used them once each day to read (Mann Whitney U, $p < 0.001$). Reading frequency using PELVAs compared to optical low vision aids is shown in Figure 6.7.

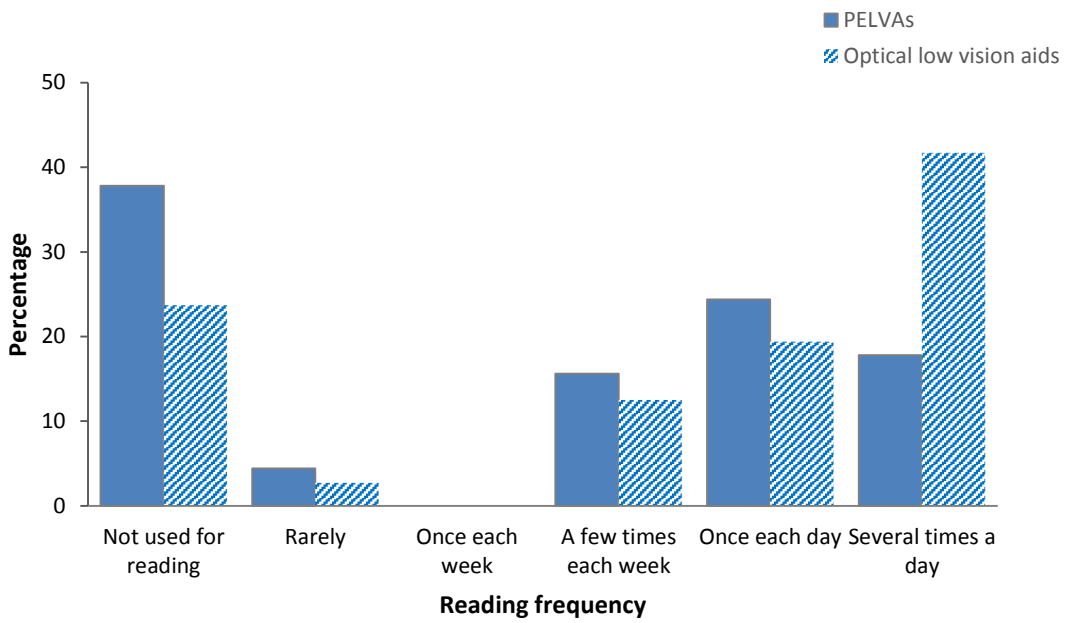


Figure 6.7: The frequency of reading of patients who used PELVAs (n=45) and patients who used optical low vision aids (n=72) (How often do you use your PELVA/ optical low vision aid for reading?, i.e. Part II of the MLVQ).

6.3.5. Reading duration using low vision aids

Reading duration (i.e. how long a patient used PELVAs/ optical low vision aids at any one time for reading i.e. Part II of the MLVQ) was evaluated. PELVAs were used more for a longer reading duration (Mann Whitney U, $p < 0.001$). The median duration of reading using PELVA was 'up to 30 minutes' (IQR from 'up to 10 minutes' to 'more than 30 minutes'), i.e. on average patients prescribed a PELVA used it for up to 30 minutes at any one time for reading. The median duration of reading using Optical low vision aids was 'up to 5 minutes' (IQR from 'up to 5 minutes' to 'up to 30 minutes'), i.e. on average patients prescribed optical low vision aids used them for up to 5 minutes at any one time for reading. There was a significant difference in reading duration of patients who used

PELVAs compared to patients who used optical low vision aids (Mann Whitney U, $p < 0.001$). Reading duration using PELVAs compared to optical low vision aids is shown in Figure 6.8.

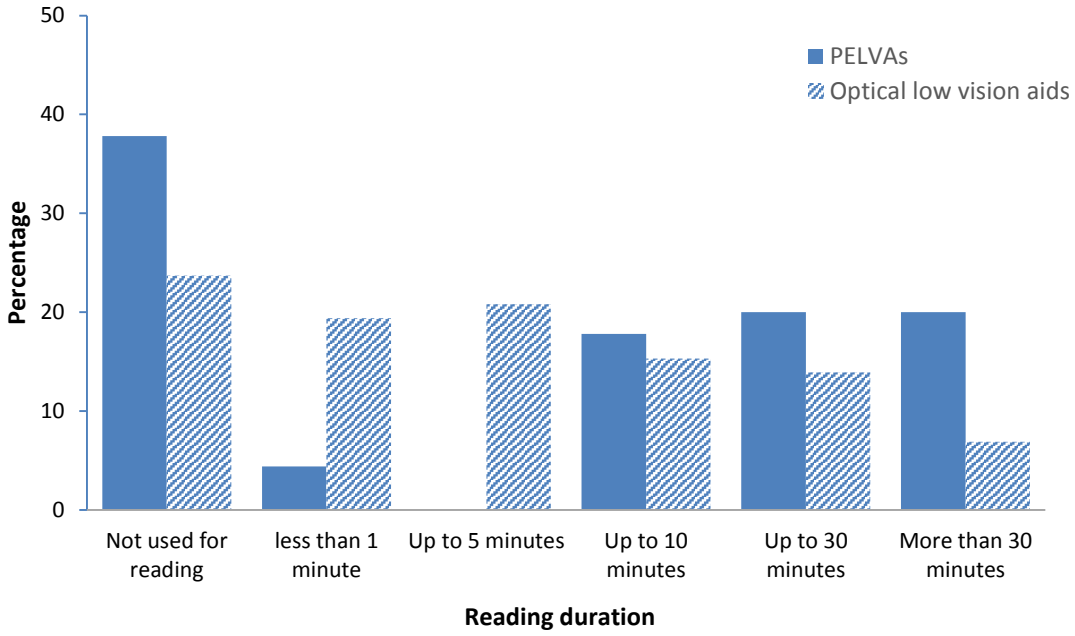


Figure 6.8: Duration of reading of patients who used PELVAs (n=45) and patients who used optical low vision aids (n=72) (How long can your PELVA/ optical low vision aid be used for reading at any one time?, i.e. Part II MLVQ).

6.3.6. The use of PELVAs by patients who used both PELVAs and optical low vision aids

The use and rating was compared for patients who used both PELVAs and optical low vision aids (n=29). Patients used PELVAs, but not optical low vision aids for all of the following tasks: doing a special hobby, identifying money, signing their own names, and reading markings on dials (Table 6.3).

The median rating of PELVAs (4 i.e. extremely helpful) was significantly higher than optical low vision aids (3 i.e. moderately helpful) for tasks performed (Wilcoxon signed rank test, $p < 0.001$).

It seems that when patients had the choice whether to use PELVAs or optical low vision aids for a number of near vision tasks; they tend to use PELVAs rather than optical low vision aids in order to read shop prices, labels, or tickets (McNemar's, $p = 0.028$), to read instructions on packets, tins, bottles etc. (McNemar's, $p = 0.032$), to sign their own name (McNemar's, $p = < 0.001$), and to do a special hobby (McNemar's, $p = 0.004$) (Table 6.3).

In comparison, significantly more patients used optical low vision aids compared to PELVAs in order to read large print books (McNemar's, $p < 0.001$), and to read letters, cards, bank statements, etc. (McNemar's, $p < 0.001$) (Table 6.3).

Among 29 patients who used both PELVAs and optical low vision aids, the rating of PELVAs (median = 4) was significantly higher for reading shop prices, labels or tickets compared to optical low vision aids (median = 1) (Wilcoxon signed rank test, $p < 0.001$). Whereas, the rating of optical low vision aids (median = 4) was significantly higher than PELVAs rating (median = 3) for reading instructions on packets, tins, bottles, or medicines (Wilcoxon signed rank test, $p < 0.001$). The use and rating of using both PELVAs and optical low vision aids by 29 patients is shown in Table 6.3.

Task	Frequency of use % (Number) of patients who used them for named tasks)			Median rating		
	PELVAs (n=29)	Optical low vision aids (n=29)	p-value	PELVAs (n=29)	Optical low vision aids (n=29)	p-value
1. Reading ordinary print books, newsprint, magazines, TV times	41.4%	41.4% (12)	1.000	3	3	0.564
2. Reading large print books, large print newspapers, or newspaper headlines	31% (9)	41.4% (12)	<0.001*	4	4	1.000
3. Reading letters, cards, bank statements, other correspondence	31% (9)	41.4% (12)	<0.001*	4	4	0.083
4. Reading their own writing	0	0	-	NE	NE	-
5. Reading instructions on packets, tins, bottles, medicines, etc	41.4%	10.3% (3)	0.032*	3	4	<0.001**
6. Reading shop prices, label, or tickets	72.4%	31% (9)	0.028*	4	1	<0.001**
7. Reading the markings on dials—eg, on the cooker, radio, hi-fi, washing machine, etc	10.3% (3)	0	0.250	4	NE	-
8. Reading the telephone directory to check numbers	0	0	-	NE	NE	-
9. Reading the time on their watch	0	0	-	NE	NE	
10. Filling in forms, cheques, cards, etc	0	0	-	NE	NE	-
11. Signing their own name	41.4%	0	<0.001*	4	NE	-
12. Writting their own letters	0	0	-	NE	NE	-
13. Identifying money	10.3% (3)	0	0.250	4	NE	-
14. Sewing, knitting/ or mending	0	0	-	NE	NE	-
15. Doing a special hobby	31% (9)	0	0.004*	3	NE	-
Rating: 4= extremely helpful, 3= moderately helpful, 2= slightly helpful, 1 = not helpful 0 = patients did not use the low vision aid for the task performed * p-value is significant (McNemar's test, $p < 0.05$) ** p-value is significant (Wilcoxon signed rank test, $p < 0.05$) – not calculated NE: rating of low vision aids was not evaluated (NE) as patients did not used low vision aids (PELVAs and/ or optical) for these tasks						

Table 6.3: The use and median rating of PELVAs compared to optical low vision aids, by 29 patients who used both PELVAs and optical low vision aids.

The frequency of reading using PELVAs compared to optical low vision aids by 29 patients who used both devices is shown in Figure 6.9. In terms of reading frequency (i.e. how often a patient used PELVAs/ optical low vision aids for reading i.e. Part II of the MLVQ), patients tended to use optical low vision aids more frequently if they had both PELVAs and optical low vision aids. The median frequency for using optical low vision aids was 'several times each day' (IQR from 'once each day' to 'several times each day') compared to median frequency of 'once each day' for using PELVAs (IQR from 'once each day' to 'several times each day') (Wilcoxon signed rank test, $p < 0.001$).

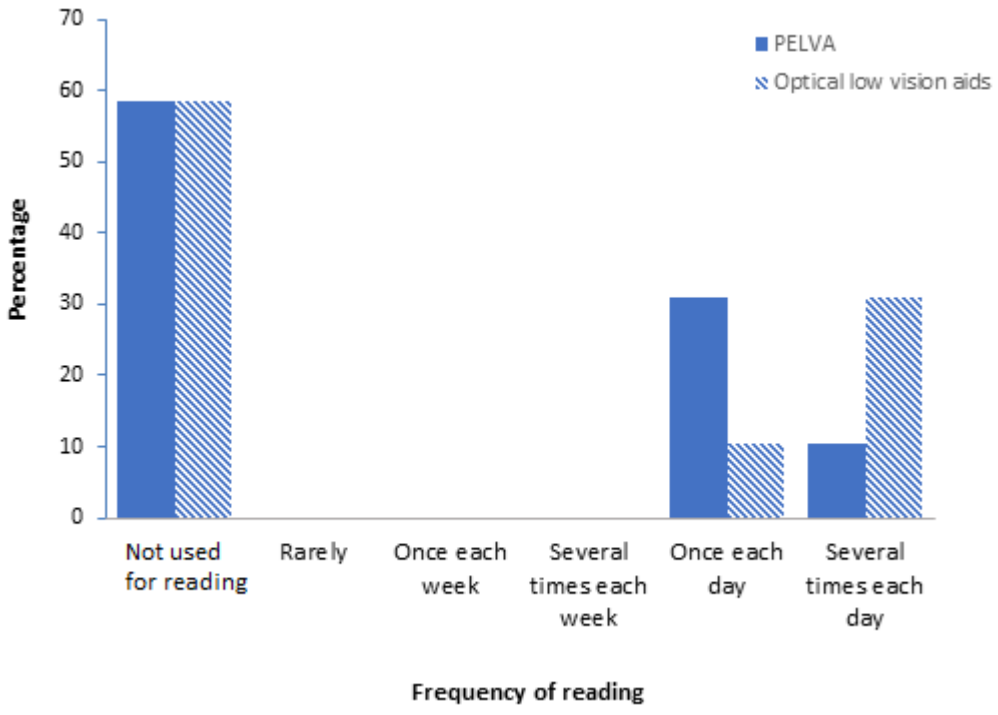


Figure 6.9: The frequency of reading of patients (n=29) who used both PELVAs and optical low vision aids (How often do you use your PELVA/ optical low vision aid for reading?, i.e. Part II of the MLVQ).

The duration of reading (i.e. how long a patient used PELVAs/ optical low vision aids at any one time for reading i.e. Part II of the MLVQ) using PELVAs compared to optical low vision aids by 29 patients who used both devices is shown in Figure 6.10 and Table 6.4. Patients used PELVAs to read for a longer duration compared to optical low vision aids. Median reading duration using PELVAs at any one time for reading was more than 30 minutes (IQR from 'up to 30 minutes' to 'more than 30 minutes') compared to median reading duration of up to 30 minutes (IQR from 'less than one minute' to 'more than 30 minutes') for using optical low vision aids at any one time for reading (Wilcoxon signed rank test, p = 0.01). For example, 31% (9) of 29 used PELVAs to read for duration of more than 30 minutes compared to 17.2% (5) of 29 used optical low vision aids to read for the same duration.

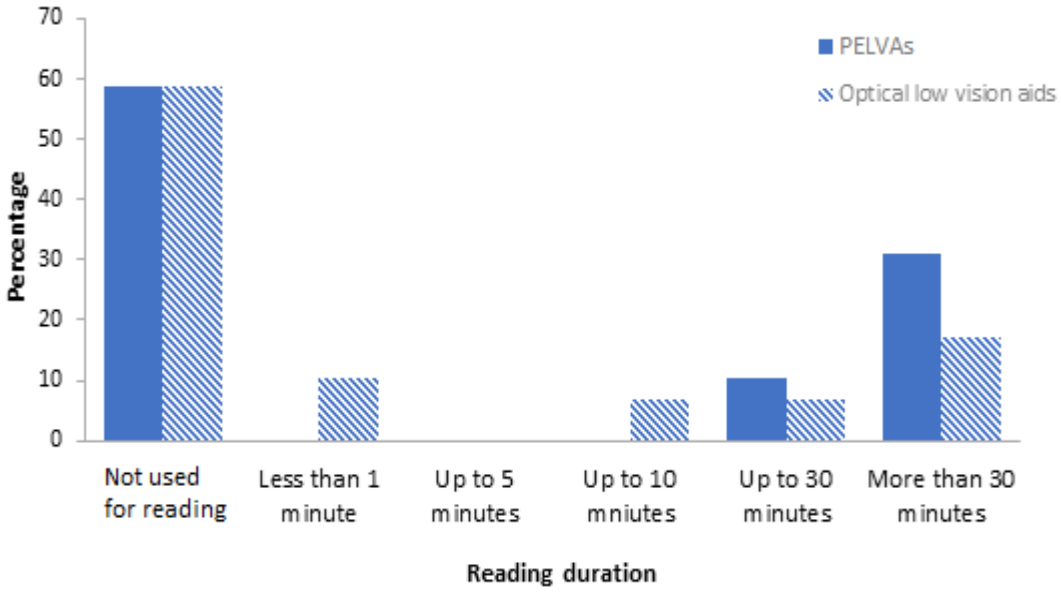


Figure 6.10: Reading duration of patients (n=29) who used both PELVAs and optical low vision aids (How long can your PELVA/ optical low vision aid be used for reading at any one time?, i.e. Part II MLVQ).

Reading duration	PELVAs Percentage (number)	Optical low vision aids Percentage (number)
Not used for reading	58.6% (17)	58.6% (17)
Less than 1 minute	0	10.3% (3)
Up to 5 minutes	0	0
Up to 10 minutes	0	6.9% (2)
Up to 30 minutes	10.3% (3)	6.9% (2)
More than 30 minutes	31.0% (9)	17.2% (5)

Table 6.4: Reading duration of patients (n=29) who used both PELVAs and optical low vision aids (How long can your PELVA/ optical low vision aid be used for reading at any one time?, i.e. Part II MLVQ).

6.4. Discussion

This is an evaluation of the use and self-reported satisfaction of PELVAs and optical low vision aids for patients with a visual impairment attending the LVSW in the year 2011/2012, using the MLVQ.

Out of 88 patients who were interviewed, 18.2% had PELVAs but not optical low vision aids, 48.9% had optical low vision aids but not PELVAs, and 33% had both PELVAs and optical low vision aids.

The majority of patients used their low vision aids daily and many used them several times a day. However, quite a large proportion of patients with PELVAs were not using them, e.g. 37.8% (17 out of 45) did not use their PELVAs for reading (Figure 6.9). Goodrich et al. (2006) found that there was a significant improvement in reading speed after the prescription of optical or electrical low vision aids with training sessions. No training was provided as part of the LVSW, and patients were just given basic instructions. Goodrich et al. (1976) also found that some PELVAs have technical faults after 2 years and so this may be a factor. Further investigation into why people have stopped using PELVAs is needed and the devices repaired or recovered as these are expensive devices, which could be loaned to other patients. Harper et al. (1999) reported that 81-90% of patients with visual impairment were prescribed at least one low vision aid, although it is known that many of them discontinue use after prescription and so follow-up is important.

Harper et al. (1999) found that patients that had optical devices often had more than one device and suggested this was because they were task specific; therefore patients would need more than one device to accomplish daily living tasks. This study found that most people 64.4% (29 out of 45) with PELVAs also had optical low vision aids. Therefore, although a PELVA can be used to perform a larger number of tasks because a range of magnifications is available, many patients use optical devices as well. This may be due to preference for a task or because of practical issues such as where they are positioned in their home, or delay in turning a PELVA on or charging it up.

Goodrich et al. (1980) reported that patients used optical aids in order to find a specific item and CCTVs for detailed viewing. They found that optical low vision aids were used for 'spotting' tasks or in cases where portability is important (Goodrich et al., 1980). In this study the distinction was not so clear and patients used PELVAs and optical low vision aids for spotting tasks such as reading shop prices, labels or tickets; reading instructions on packets, tins, or medicines; signing their own name; and doing a special hobby. However for these tasks, PELVAs were significantly more frequently used (i.e. when they had both and the option many chose the PELVA for these tasks). This might be because PELVAs are more portable than CCTVs and so have many of the advantages of optical low vision aids. PELVAs also provide contrast enhancing properties that optical devices don not and so would be useful for poor contrast tasks. However, there was not a clear preference for PELVAs and so other factors must be having an influence of their choice of device. It may be that patients who choose a PELVA for this type of task have reduced contrast sensitivity.

On the other hand, a greater percentage of people also chose to use optical devices compared to PELVAs for sustained reading tasks such as reading ordinary print books; reading large print books; and reading letters, cards and bank statements. Interestingly, patients used PELVAs less frequently but for a longer duration for reading compared to optical low vision aids. Optical low vision aids were also rated as more helpful than PELVAs for reading ordinary print books; reading instructions on packets; and doing a special hobby (Mann Whitney U, $p < 0.05$).

Although optical low vision aids were rated as moderately helpful (the median rating of optical low vision aids for all tasks performed was 3) and can be used for different tasks as explained earlier in this study, as the magnification of optical low vision aids increases; aberrations increase and the field of view constricts, also optical low vision aids do not enhance contrast manipulation (Culham et al., 2004). This might explain why patients in this study tended to rate PELVAs higher for most tasks performed and to use them for a longer reading duration. Culham et al. (2009) reported that comfort of using low vision aids was important but magnification was predictive of rating low vision aids.

Goodrich et al. (1980) found that there was no difference in reading speed between CCTVs and optical low vision aids, but reading duration was three times longer when patients used CCTVs compared to optical low vision aids. Goodrich and Kirby (2001) a higher reading speed and a longer reading duration were found using both of hand-held and stand-mounted CCTVs compared to optical low vision aids, and no differences were

found between both types of CCTVs. Peterson et al. (2003) found that electronic vision enhancement systems improved reading speed and duration. Reading speed and duration were higher using stand electronic vision enhancement systems compared to optical low vision aids and head-mounted devices (Peterson et al., 2003). Peterson et al. (2003) found that map tracking and identification of medicine labels was faster when patients used optical low vision aids and stand electronic vision enhancement system. Patients found that locating a column task was faster using optical low vision aids compared to electronic vision enhancement systems. (Peterson et al., 2003). Electronic vision enhancement systems were described as helpful by patients in terms of improving reading speed and acuity. However, electronic vision enhancement systems with a head-mounted device had a rating similar to optical magnifier for tasks including tracking from one column of print to the next, following a route on a map and locating a specific feature, and identifying specific information such as medication type (Peterson et al., 2003).

In this study 33% of patients had both PELVAs and optical low vision aids. Overall for all tasks performed, patients who had both PELVAs and optical low vision aids (n=29) found them useful. However, PELVAs were found to be slightly more helpful than optical low vision aids for tasks performed (median rating of PELVAs was 'extremely helpful', compared to 'moderately helpful' for optical low vision aids (Wilcoxon signed rank test, $p < 0.001$).

Of those interviewed who used optical low vision aids (n=72), the majority used hand-held magnifiers (87.7%), the second most frequently used aids were stand magnifiers (27.8%), jewellers eye glasses (6.9%), and spectacle mounted devices (2.8%). Some patients (23.6%) used more than one optical low vision aid. Crossland and Silver (2005) found that patients were prescribed at least one low vision aid; hand-held magnifiers 47%, spectacle mounted devices 2%, high reading additions 15%, stand magnifiers 34%, other low vision aids 2%. They also reported that illuminated magnifiers accounted for 39% of hand-held magnifiers, and 40% off stand magnifiers. Electronic low vision aids were not included in the Crossland and Silver (2005) study as it was only available for demonstration. Our findings agree with Crossland and Silver (2005) in that the majority of the prescribed optical low vision aids were hand-held magnifiers. However, they found a larger proportion of patients who were prescribed optical magnifiers (84%) compared to our results (71%); as PELVAs and electronic low vision aids were not included in their study. In addition, this study sought to ensure a larger number of people with PELVAs were included and so the sample is not representative of the service users.

In our study only 23.6% (16.7% illuminated hand-held, and 6.9% illuminated stand) of patients used illuminated optical low vision aids. This contradict the ere dispensed in the LVSW were illuminated, it also did not agree with the larger proportion of illuminated hand-held (39%) and illuminated stand (40%) magnifiers that were prescribed in the Crossland and Silver study. This might be because of the way the questions were asked. In the Manchester Low Vision Questionnaire there was not an option to choose an

illuminated hand magnifier hence people may have described an illuminated hand magnifier as a hand magnifier or an illuminated magnifier. Most illuminated magnifiers are hand or stand magnifiers; hence including these as options in the MLVQ is suggested. Also, our study was a pilot study which might not be representative of all patients with visual impairment.

Out of 88 patients interviewed, there were 42% who used 'other low vision aids' including non-optical, substitution and electronic low vision aids along with PELVAs and/ optical low vision aids. The majority of patients who used 'other low vision aids' were optical low vision aids users (43%) compared to PELVAs users (19%) (Chi squared, $p < 0.001$). This agree with the fact that optical low vision aid alone might not be appropriate for many tasks, and a patient might need more low vision aids to accomplish several tasks. Other low vision aids used by patients in this study included CCTVs, computers, appropriate lighting, pen, mouse, talking books, talking watches, large print telephone directory, electronic books, e-readers, and large print texts. Some patients used more than one of the 'other low vision aids'. In our study, there were 16 of patients who used CCTVs; this is equivalent to 18.2% (n=88). This was lower than Goodrich et al. (1980) findings. Goodrich et al. (1980) found that 50% (48 of 96) of US veterans who used CCTVs used also optical low vision aids. It might be because patients in our study used different types of electronic low vision aids including PELVAs, computers, e-readers, e-books, etc. In addition veterans are often younger and more likely to be male than the low vision population in Wales.

Although the results may not be representative of all patients with a visual impairment using the LVSW, this study was important. It compared the use and rating of both PELVAs and optical low vision aids from the users' perspective for a number of near vision tasks. Patients' feedback on the prescribed low vision aids was important in order to update clinicians on what they are used for. Experience and trying low vision aids is important in order to have a perspective of the practicability and limitations of existing low vision aids for a range of tasks and provide more realistic expectation of what can be achieved from using a particular low vision aid.

The results haven't shown any clear trends of use of PELVAs or optical devices and so it is important for clinicians to encourage patients to try using PELVAs and to discuss with them a range of tasks including reading books or newspapers, reading shop prices, instructions etc. that proved in this study to be helpful.

The limitations of this study included the low recruitment rate which might be explained by: a) the cohort of study were elderly and many of them have other disabilities such as hearing loss or mobility restrictions besides visual impairment, b) lack of somebody to help them to arrange the interview, c) worsening of their vision, d) discontinuation of low vision aids usage, or e) the form of the MLVQ that was used in the interview excluded three tasks related to distance vision, therefore it might not have the same validity as if the original MLVQ was used. The prescribing for low vision aids was initially made in the year 2011/2012. This study was conducted in 2014; many patients could have discontinued the use of prescribed devices either because of change of vision,

limitations of prescribed aids to help them perform required tasks, or ergonomics of some devices. Patients' preference of using a low vision aid might be affected by several factors such as performance of visual aids including magnification and image quality, ergonomics, cost, size, weight, portability, ease of use, age of users, ocular conditions, or the onset of visual impairment (Culham et al., 2009). Those factors were not evaluated in this study and would be better explored using qualitative techniques such as a semi structured interview.

Phone interviews can be less personal and more anonymous. However, they may be more convenient for elderly patients with visual impairment rather than conducting a face-to-face interview, because it could be difficult for most of them to arrange a visit to the clinic to be interviewed. A phone interview has an advantage that any questions can be explained when necessary which is not possible if patients were asked to fill a questionnaire and return it in the post. However, some patients had hearing difficulty which might have prevented participating in phone-interviews. Semi-structured interviews may have been more valid, but they are time consuming, expensive, and they can be difficult to generalize (Opdenakker, 2006).

6.5. Conclusion

A larger proportion of patients used optical low vision aids compared to PELVAs and a third of the patients used both PELVAs and optical low vision aids. Some patients used other low vision aids. PELVAs were used more frequently for reading shop prices, reading instructions on packets, signing their own names, and doing a special hobby compared to optical devices. PELVAs were significantly more helpful than optical low vision aids for the near vision tasks performed. PELVAs were used less frequently but for a longer duration when reading compared to optical low vision aids. Clinicians are encouraged to demonstrate the benefits of using these devices, and the group of tasks that can be performed using a PELVA. Further investigations of the factors that affect patient preference for using low vision aids for each task should be explored. Also, the cost effectiveness of PELVAs and optical low vision aids should be compared.

CHAPTER 7: Investigation of the factors (visual functions and/ or devices parameters) that affect reading performance of people with simulated visual impairment using low vision aids (pocket and portable electronic low vision aids, and optical low vision aids)

7.1. Introduction

Reading difficulty is the most common complaint in people with visual impairment (Rubin, 2013). Rubin (2013) found that reading difficulty was the reason for 60% of patients to be referred to low vision practices. Literature available about the effectiveness of low vision aids has been focused on improvement in reading ability or speed by comparing the reading ability and/ or performance (e.g. critical print size, reading acuity and reading speed) with and without visual aids (Rubin, 2013).

To our knowledge, no one has evaluated factors affecting reading performance using PELVAs, and no one has compared PELVAs to optical low vision aids in terms of reading performance. In Chapter 6, we reported that patients with visual impairment used PELVAs less frequently for reading, but for a longer reading duration at any one time. Therefore, it was important to explore factors affecting reading performance using PELVAs.

In Chapter 4, we reported that some PELVAs significantly improved the luminance contrast of high and low contrast letters, and we hypothesize this will have an influence on reading performance. In addition, as PELVAs feature contrast enhancement and a

large screen compared to optical low vision aids, we hypothesize that PELVAs may provide a higher reading speed.

The aim of this study was to investigate visual functions and/ or devices parameters that affect the reading performance of people with visual impairment using low vision aids (PELVAs and optical low vision aids).

The objectives of this study were:

1) To measure threshold near visual acuity of people with simulated visual impairment, using PELVAs and optical low vision aids.

2) To measure high and low contrast visual acuities of people with simulated visual impairment, using PELVAs and optical low vision aids.

3) To evaluate the field of view of people with simulated visual impairment (by counting the number of visible characters), using PELVAs and optical low vision aids.

4) To measure the reading speed of people with simulated visual impairment, using both PELVAs and optical low vision aids.

7.2. Methods

This pilot study aimed to investigate factors (visual functions and/ or device parameters) that affect reading performance of people with simulated visual impairment using low vision aids (PELVAs and optical devices).

7.2.1. Ethics

The study protocols, the Patient Information Sheets and Consent Forms were approved by the School of Optometry and Vision Sciences Ethical Committee (Project no. 1352 24th October 2014) (Appendix IV).

7.2.2. Participants

A total of 10 normally sighted participants, aged between 20 and 30 years old were recruited. This age group was chosen to exclude the influence of age on reading performance. Participants were excluded if they had a history of abnormal ocular conditions, visual impairment or physical disability or limitation that could affect handling or use of low vision aids.

7.2.3. Location

Participants were examined in the Low Vision Clinic at the School of Optometry and Vision Sciences, Cardiff University.

7.2.4. Low vision aids used

A PELVA (Compact+) (i.e. PELVA B in Chapters 3 and 4) with fixed magnification levels 5X, 7.5X and 10X, and optical illuminated stand magnifiers (Eschenbach) with magnification 5X, 7X and 10X were used. The participants were asked to select the magnification level they were able to read with at the given distance (40 cm) using the PELVA, and the participant choose an illuminated stand magnifier themselves in the same way as the PELVA. The participants were advised to put the PELVA or the optical illuminated stand magnifier directly on the text/ chart. The accommodation was not controlled.

7.2.4. Simulation of visual impairment

Simulators

Three simulator glasses were used to mimic visual impairment, these included:

1) Moderate visual impairment simulator. This was achieved by adding plus lenses, to reduce participants distance visual acuity to 0.60 Log MAR. This was the median distance visual acuity of people who were not prescribed a PELVA (Chapter 5).

2) Severe visual impairment simulator. This was achieved by adding plus lenses, to reduce participants distance visual acuity to 0.90 Log MAR. This was the median distance visual acuity of people who were prescribed a PELVA (Chapter 5).

3) Reduced contrast sensitivity simulator (cortical cataract simulator). The contrast sensitivity reduction was achieved by using glasses with a semi-transparent (cloudy) plastic filter.

With all simulators participants' near visual acuity was reduced.

7.2.5. Clinical assessment

Baseline (without simulators, without low vision aids)

Baseline best corrected binocular Log MAR distance visual acuity at 2 metres, contrast sensitivity using Pelli-Robson chart at 1 meter, threshold near visual acuity using Bailey-Lovie near visual acuity chart at 40 cm, and reading speed using IREST at 40 cm were measured for all participants.

With simulators (without low vision aids)

Binocular Log MAR distance visual acuity at 2 metres, contrast sensitivity using Pelli-Robson chart at 1 meter, and threshold near visual acuity using Bailey-Lovie near acuity chart at 40 cm, high contrast Colenbrander near visual acuity at 40 cm, low contrast Colenbrander near visual acuity at 40 cm, and reading speed using IREST at 40 cm were measured with each simulator (without low vision aids, while the habitual correction was worn).

With simulators and low vision aids

At 40 cm, threshold near visual acuity using a Bailey-Lovie near acuity chart, high and low contrast near visual acuity using a high and a low contrast Colenbrander chart, the number of visible characters seen (i.e. the edge of the PELVA screen/ or the edge of the optical low vision aid lens was placed at the beginning of the IREST text and participants were asked to count the number of characters including spaces that they were able to see without moving their head), and reading speed using IREST were measured with both a PELVA and an illuminated stand magnifier.

A fixed distance of 40 cm was chosen for all near charts for consistency because IREST reading chart were designed to be used at 40 cm (the distance at which most people read). The Bailey-Lovie near visual acuity was calculated in Log MAR for a distance of 40 cm.

7.3. Results

A total of ten normally sighted participants were tested (mean age 23.2±3.61 years, binocular distance visual acuity -0.30±0.00 Log MAR, contrast sensitivity 1.94±0.05, Bailey-Lovie near visual acuity was 0.08±0.07, reading speed 325.27±46.65 words/ minute). Data (age, binocular Log MAR distance visual acuity, Bailey-Lovie near visual acuity, high and low contrast, Colenbrander near visual acuities, reading speed, and number of visible characters) were normally distributed (Shapiro-Wilk test, $p = 0.615$).

The moderate visual impairment (0.6 Log MAR distance visual acuity) was achieved by using plus lenses (mean +4.25 dioptres (D), range +3.75 to + 5.25). The severe visual impairment (0.90 Log MAR distance visual acuity) was achieved by using plus lenses (mean +7.50 D, range +6.00 to +9.50).

Of the three magnification levels (5X, 7.5X, and 10X) of the PELVA, all participants chose the lowest magnification level (5X magnification), and they chose a 5X Eschenbach illuminated stand magnifier.

It would not be appropriate to compare magnifiers with different equivalent power, because the 5X magnification of the PELVA is not equivalent to the 5X magnification of the stand magnifier. With the fixed focus stand magnifier used in this study the lens to object distance was less than the focal length of the lens. The optics of the stand magnifier is described below.

The stand magnifier optics:

The 5X Eschenbach illuminated stand magnifier was labelled by the manufacturer with 5X magnification, and equivalent power of 20 D. In general, Eschenbach assumes an image to eye distance of 400 mm (Jonston 2003, Eschenbach Optik GmbH 2015).

The focal length of a 20 D stand magnifier is 5 cm. For a stand magnifier the lens to object distance is less than the focal length of the lens and for the stand magnifier used in this study it was 3.6 cm. Therefore, the light leaving the stand magnifier will be divergent.

The vergence of light reaching the stand magnifier from the text/ object (L) at a distance of 3.6 cm was:

L = 1/ - stand height in metres (Jackson and Wolffsohn, 2007)

L = 1/ -0.036

L = -27.80 D.

The vergence of light leaving the stand magnifier (L') with lens power +20.00 D was:

L' = L + Fm (Jackson and Wolffsohn, 2007)

L' = -27.80 + (+20.00)

L' = - 7.80 D.

Where Fm is the dioptric power of the magnifier.

The image distance (I') was:

$$I' = 1 / L' \qquad \text{(Jackson and Wolffsohn, 2007)}$$

$$I' = 1 / -7.80$$

$$I' = -12.80 \text{ cm.}$$

The enlargement was:

$$= -12.80 / -3.60$$

$$= 3.6X \text{ magnification.}$$

Therefore the stand magnifier labelled as 5X magnification, gave an equivalent magnification of 3.6X.

With this, if the participant's eye was against the stand magnifier (eye to magnifier distance (z) was zero), the image that was created by the stand magnifier alone would be at -12.8 cm in front of the eye and a 7.80 D addition/ accommodation would be required to neutralize the divergent light. The equivalent power (Fe) would be:

$$Fe = Fm + Fa - z * Fm * Fa \qquad \text{(Jackson and Wolffsohn, 2007)}$$

$$Fe = 20.00 + 7.80 - 0 * 20 * 7.80$$

$$Fe = 27.80 \text{ D.}$$

Where Fm is the magnifier power, Fa is the addition or accommodation, z is the magnifier to eye distance.

Enlargement ratio= Fe / 4 (Jackson and Wolffsohn, 2007)

= 27.80 / 4

= 6.95 X.

However, if the stand magnifier to the participant's eye distance was 35 cm (40 cm eye-to-text); the image would be positioned at:

= z + l' (Jackson and Wolffsohn, 2007)

= -35 + (-12.8)

= -47.80 cm.

The required accommodation/ add would be:

= 1 / 0.478

= 2.10 D.

That means a 2.10 D would be needed to focus the divergent light on the retina. As all the participants are young, this would be achieved by participants' accommodation, which was not controlled or measured in this study.

Assuming 2.10 D of accommodation; the enlargement ratio of the accommodation system would be:

$$Fe = Fm + Fa - z * Fm * Fa \quad \text{(Jackson and Wolffsohn, 2007)}$$

$$= 20.00 + 2.10 - 0.35 * 20 * 2.10$$

$$Fe = 7.40 \text{ D.}$$

$$\text{Enlargement} = 7.40/ 4$$

$$= 1.85X.$$

That means if participants used 2.10 D of their accommodation to focus the image on the retina, the accommodation would give an additional 1.85X.

The accommodation/ addition cannot be greater than the divergence of light leaving the stand magnifier lens, or a blurred image of the text/ object would be formed on the retina. Participants would still accommodate. The accommodation was not controlled in this study.

Assuming participants would not use their accommodation to focus the image and the required 2.10 D to focus the image was used of the +4.25 D that was added as moderate visual impairment simulators; with the remaining +2.15 D the participants Baily-Lovie near visual acuity was blurred to 0.54±0.3 Log MAR. This means the moderate visual impairment simulator was enough to blur near visual acuity.

7.3.1. Moderate visual impairment simulator (0.60 Log MAR distance visual acuity)

With the 0.60 Log MAR simulator, near visual acuity measured using a Bailey-Lovie near acuity chart significantly improved with the PELVA and the optical low vision aid; from

0.77±0.16 Log MAR to 0.04±0.08 using the PELVA (Paired sample t-test, p < 0.001) and 0.54±0.30 using the optical low vision aid (Paired sample t-test, p < 0.001) (Table 7.1).

Moderate visual impairment (0.60 Log MAR distance visual acuity) simulator	Assessment	Without low vision aids	With PELVA (5X magnification)		With optical low vision aid (3.6X equivalent magnification)	
		mean±SD	mean±SD	P-value[1]	mean±SD	P-value[2]
	Distance visual acuity (Log MAR)	0.6±0.006	-	-	-	-
	Contrast sensitivity at 1 meter (Pelli-Robson)	1.50±0.09	-	-	-	-
	Bailey-Lovie near visual acuity (Log MAR)	0.77±0.16	0.04±0.08	< 0.001*	0.54±0.30	< 0.001*
	High contrast Colenbrander near visual acuity (Log MAR equivalent)	0.52±0.18	-0.08±0.04	< 0.001*	0.03±0.12	< 0.001*
	Low contrast Colenbrander near visual acuity (Log MAR equivalent)	0.88±0.22	0.03±0.12	< 0.001*	0.3±0.19	< 0.001*
	Reading speed (words/ minute)	NM	169.91±33.56	-	120.16±32.21	-
	Number of visible characters	-	21.8±1.69	-	13.50±2.17	-

Table 7.1: Visual assessment with moderate visual impairment simulator, with and without low vision aids. P-value[1] the significance of difference between the PELVA and without low vision aids (Paired sample t-test). P-value[2] the significance of difference between the optical low vision aid and without low vision aids (Paired sample t-test). * The difference is significant (p-value < 0.05). NM = not measurable.

High contrast near visual acuity using a Colenbrander chart significantly improved from 0.52±0.18 Log MAR equivalent to -0.08±0.04 Log MAR equivalent using the PELVA (Paired sample t-test, p < 0.001) and to 0.03±0.12 Log MAR equivalent using the optical low vision aid (Paired sample t-test, p < 0.001) (Table 7.1).

Low contrast near visual acuity using a Colenbrander chart significantly improved from 0.88±0.22 Log MAR equivalent to 0.03±0.12 using the PELVA (Paired sample t-test, p <

0.001) and to 0.03±0.19 using the optical low vision aid (Paired sample t-test, $p < 0.001$) (Table 7.1).

With 0.60 Log MAR simulator, participants could not see clearly enough to be able to read the IREST passages at 40cm, therefor reading speed could not be measured at 40cm, but the reading speed was significantly improved using the PELVA to 169.9±33.56 words/ minute, and with the optical low vision aid to 120.16±32.21 words/ minute (Table 7.1). The reading speed was significantly faster using the 5X magnification PELVA compared to the 3.6X magnification optical low vision aid (Paired sample t-test, $p < 0.001$).

The number of visible characters including spaces was 21.8±1.69 characters using the PELVA and 13.5±2.17 characters using the optical low vision aid (Table 7.1).

7.3.2. Severe visual impairment simulator (0.90 Log MAR distance visual acuity)

With the 0.90 Log MAR simulator, near visual acuity measured using a Bailey-Lovie near acuity chart significantly improved from 1.22±0.97Log MAR to 0.46±0.12 using the PELVA (Paired sample t-test, $p < 0.001$) and to 0.83±0.22 using the optical low vision aid (Paired sample t-test, $p < 0.001$) (Table 7.2).

Severe visual impairment (0.90 Log MAR distance visual acuity) simulator	Assessment	Without low vision aids	With PELVA (5X magnification)		With optical low vision aid (3.6X equivalent magnification)	
		mean±SD	mean±SD	P-value[1]	mean±SD	P-value[2]
	Distance visual acuity (Log MAR)	0.90±0.01	-	-	-	-
	Contrast sensitivity at 1 meter (Pelli-Robson)	1.32±0.16	-	-	-	-
	Bailey-Lovie near visual acuity (Log MAR)	1.22±0.1	0.46±0.12	< 0.001*	0.83±0.22	< 0.001*
	High contrast Colenbrander near visual acuity (Log MAR equivalent)	0.69±0.24	0.00±0.1	< 0.001*	0.34±0.13	< 0.001*
	Low contrast Colenbrander near visual acuity (Log MAR equivalent)	0.98±0.31	0.31±0.20	< 0.001*	0.94±0.13	0.521
	Reading speed (words/ minute)	NM	110.62±35.03	-	56.38±3.78	-
	Number of visible characters	-	22.89±2.42	-	9.78±1.72	-

Table 7.2: Visual assessment with severe visual impairment simulator, with and without low vision aids. P-value[1] the significance of difference between the PELVA and without low vision aids (Paired sample t-test). P-value[2] the significance of difference between the optical low vision aid and without low vision aids (Paired sample t-test). * The difference is significant (p-value < 0.05). NM = not measurable.

High contrast near visual acuity using a Colenbrander chart significantly improved from 0.69±0.24 to 0.00±0.01 Log MAR equivalent using the PELVA (Paired sample t-test, $p < 0.001$), and to 0.34±0.25 Log MAR equivalent using the optical low vision aid (Paired sample t-test, $p < 0.001$) (Table 7.2).

Low contrast near visual acuity using a Colenbrander chart significantly improved from 0.98±0.31 to 0.31±0.20 Log MAR equivalent using the PELVA (Paired sample t-test, $p < 0.001$), but did not significantly change 0.94±0.13 Log MAR equivalent (Paired sample t-test, $p = 0.521$) using the optical low vision aid (Table 7.2).

With 0.90 Log MAR simulator, participants did not see clearly enough to be able to read the IREST passages at 40cm, therefore reading speed could not be measured at 40cm, but the reading ability was significantly improved using the PELVA (110.62±35.03 words/ minute), and the optical low vision aid (56.38±3.78 words/ minute) (Table 7.2). The reading speed was significantly faster using the 5X magnification PELVA compared to the 3.6X magnification optical low vision aid (Paired sample t-test, $p < 0.001$).

The mean number of visible characters was 22.89±2.42 characters using the PELVA and 9.78±1.72 characters using the optical low vision aid (Table 7.2).

7.3.3. Cataract simulator (contrast reduction)

With the cataract simulator, near visual acuity measured using a Bailey-Lovie near acuity chart significantly improved from 1.17±0.10Log MAR to 0.24±0.11 using the PELVA (Paired sample t-test, $p < 0.001$), and 0.50±0.12 using the optical low vision aid (Paired sample t-test, $p < 0.001$) (Table 7.3).

	Assessment	Without low vision aids	With PELVA (5X magnification)		With optical low vision aid (3.6X equivalent magnification)	
		mean±SD	mean±SD	P-value[1]	mean±SD	P-value[2]
Cataract (reduced contrast) simulator	Distance visual acuity (Log MAR)	0.66±0.12	-	-	-	-
	Contrast sensitivity at 1 meter (Pelli-Robson)	0.9±0.08	-	-	-	-
	Bailey-Lovie near visual acuity (Log MAR)	1.17±0.1	0.24±0.11	< 0.001*	0.50±0.12	< 0.001*
	High contrast Colenbrander near visual acuity (Log MAR equivalent)	0.81±0.09	0.02±0.07	< 0.001*	0.16±0.16	< 0.001*
	Low contrast Colenbrander near visual acuity (Log MAR equivalent)	1.16±0.16	0.52±0.29	< 0.001*	1.09±0.29	0.087
	Reading speed (words/ minute)	NM	152.94±32.6	-	117.39±21	-
	Number of visible characters	-	21.67±2.78	-	11.33±3.24	-

Table 7.3: Visual assessment with cataract visual impairment simulator, with and without low vision aids. P-value[1] the significance of difference between the PELVA and without low vision aids (Paired sample t-test). P-value[2] the significance of difference between the optical low vision aid and without low vision aids (Paired sample t-test). * The difference is significant (p-value < 0.05). NM = not measurable.

High contrast near visual acuity using a Colenbrander chart significantly improved from 0.81±0.09 to 0.02±0.07 Log MAR equivalent using the PELVA (Paired sample t-test, $p < 0.001$), and 0.16±0.16 Log MAR equivalent using the optical low vision aid (Paired sample t-test, $p < 0.001$) (Table 7.3).

Low contrast near visual acuity using a Colenbrander chart significantly improved from 1.16±0.16 to 0.52±0.29 Log MAR equivalent using the PELVA (Paired sample t-test, p <

0.001), but did not improve significantly using the optical low vision aid (Paired sample t-test, p = 0.087) (Table 7.3).

Participants did not see clearly enough to be able to read the IREST at 40 cm with the cataract simulator, therefore reading speed could not be measured at 40cm, but the reading speed was significantly improved to 152.94±32.61 words/ minute using the PELVA, and 117.39±20.1 words per minute using the optical low vision aid (Table 7.3). The reading speed was significantly faster using the PELVA (5X magnification) compared to the lower magnification (3.6X) optical low vision aid (Paired sample t-test, $p < 0.001$).

The mean number of visible characters was 21.67±2.78 characters using the PELVA and 11.33±3.24 characters using the optical low vision aid (Table 7.3).

The significance of difference between the PELVA and the optical low vision aid was not compared because different equivalent magnification was used 5X magnification with the PELVA and 3.6X with the optical low vision aid.

For both the PELVA and the optical low vision aid, the reading speed with the severe visual impairment simulator was significantly lower compared to moderate visual impairment and cataract simulators (Multiple paired sample t-test, $p < 0.001$) (Figure 7.1). However, there was no significant difference (Multiple paired sample t-test, p >

0.05) between reading speed using the cataract and moderate visual impairment simulators with the PELVA and the optical low vision aid.

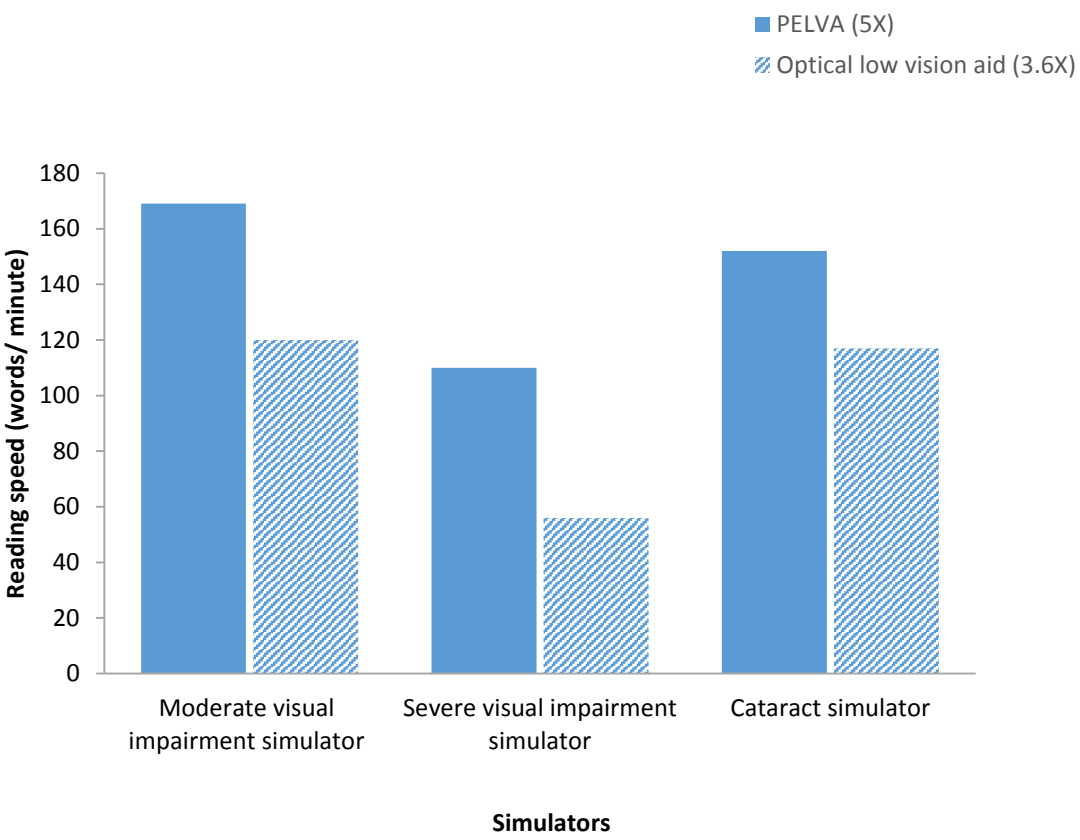


Figure 7.1: Reading speed using IREST reading chart for the three different visual impairment simulators, with the PELVA and the optical low vision aids.

Although the PELVA's Bailey-Lovie near visual acuity, high contrast Colenbrander near visual acuity, low contrast near visual acuity, reading speed, and number of visible characters were higher/ better compared to that of the optical low vision aid for all simulators (Paired sample t-test $p < 0.001$), the relationship between the 3.6X optical low vision aid and the 5X PELVA was not linear for all of: Bailey-Lovie near visual acuity

(Pearson Correlation Coefficient = 0.002, p = 0.989), high contrast Colenbrander near visual acuity (Pearson Correlation Coefficient = 0.134, p = 0.298), low contrast Colenbrander near visual acuity (Pearson Correlation Coefficient 0.221, p = 0.091), reading speed (Pearson Correlation Coefficient = 0.215, p = 0.071), and number of visible characters (Pearson Correlation Coefficient 0.051, p = 0.670). Therefore, the comparison between the PELVA and the optical low vision aid was not appropriate in this study.

7.3.4. Factors affecting reading speed

All parameters (Bailey-Lovie near visual acuity, high contrast near acuity, low contrast near acuity, reading speed, and the number of visible characters) measured in this study, were improved with the PELVA (Paired sample t-test, $p < 0.05$) using all simulators (Tables 7.1, 7.2, and 7.3). Finding the factor(s) that significantly affected reading performance with the PELVA was important, therefore, multiple regression analysis was performed.

Reading speed with simulators using the PELVA and the optical low vision aid

All of the Bailey-Lovie near visual acuity, high contrast Colenbrander near visual acuity, low contrast Colenbrander near visual acuity, and the number of visible characters were significant predictors/ factors (B-coefficient, $p < 0.05$) of reading speed**.** This was the case for the PELVA and the optical low vision aid with all simulators (Table 7.4). The statistical significance of each predictor/ factor is show in Table 7.4.

Low vision aid	Simulator	Predictor (X)	B-coefficient (B)	P-value
PELVA (5x magnification)	Moderate visual impairment simulator (adjusted R square= 0.960, p < 0.001, constant[4] 156.22)	Bailey-Lovie near visual acuity[1]	-231.97	< 0.001*
		High contrast Colenbrander acuity[2]	-104.23	< 0.001*
		Low contrast Colenbrander acuity[3]	-333.95	< 0.001*
		Number of visible characters	+15.53	< 0.001*
	Severe visual impairment simulator (adjusted R square = 0.955, p < 0.001, constant[4] 90.867)	Bailey-Lovie near visual acuity[1]	-187.89	< 0.001*
		High contrast Colenbrander acuity[2]	-125.44	< 0.001*
		Low contrast Colenbrander acuity[3]	-301.98	< 0.001*
		Number of visible characters	+10.13	< 0.001*
	Cataract simulator (adjusted R square = 0.981, p < 0.001, constant[4] 120.74)	Bailey-Lovie near visual acuity[1]	-210.44	< 0.001*
		High contrast Colenbrander acuity[2]	-35.83	< 0.001*
		Low contrast Colenbrander acuity[3]	-259.83	< 0.001*
		Number of visible characters	+12.27	< 0.001*
Optical low vision aid(3.6X equivalent magnification)	Moderate visual impairment simulator (adjusted R square = 0.853, p < 0.001, constant[4] 75.68)	Bailey-Lovie near visual acuity[1]	-199.44	< 0.001*
		High contrast Colenbrander acuity[2]	-105.83	< 0.001*
		Low contrast Colenbrander acuity[3]	-279.35	< 0.001*
		Number of visible characters	+10.27	< 0.001*
	Severe visual impairment simulator (adjusted R square = 0.82, p < 0.001, constant[4] 52.82)	Bailey-Lovie near visual acuity[1]	-172.81	< 0.001*
		High contrast Colenbrander acuity[2]	-93.56	< 0.001*
		Low contrast Colenbrander acuity[3]	-104.49	< 0.001*
		Number of visible characters	+8.37	< 0.001*
	Cataract simulator (adjusted R square = 0.811, p < 0.001, constant[4] 72.65)	Bailey-Lovie near visual acuity[1]	-191.76	< 0.001*
		High contrast Colenbrander acuity[2]	-107.10	< 0.001*
		Low contrast Colenbrander acuity[3]	-85.23	< 0.001*
		Number of visible characters	+9.25	< 0.001*

Table 7.4: Predictors of reading speed of participants with simulated visual impairment (moderate visual impairment, severe visual impairment and cataract simulators). * P-value is significant (p < 0.05).[1] Bailey-Lovie near visual acuity in Log MAR. [2] High contrast Colenbrander near visual acuity in Log MAR equivalent. [3] Low contrast Colenbrander near visual acuity in Log MAR equivalent. Regression analysis was used to analyse data. [4] Constant is the predicted reading speed when all factors/ predictors (X) equal zero. B-coefficient: The predicted reading speed increases (+) or decreases (-) by *B-coefficient, for example with the optical low vision aid, the Bailey-Lovie near visual acuity in Log MAR decrease the predicted reading speed by a factor of 191.76.

Using data in Table 7.2, for each simulator using the PELVA or the optical low vision aid reading speed can be predicted by applying:

Y = Constant + B* Bailey-Lovie near visual acuity in Log MAR + B* High contrast Colenbrander visual acuity in Log MAR + B* Low contrast Colenbrander visual acuity in Log MAR + B* Number of visible characters for each simulator, where Y is the predicted reading speed in words/ minute, the constant is the predicted reading speed when all factors (X) equal zero. For example, one the study participants with a cataract simulator and using the PELVA, had Bailey-Lovie near visual acuity of 0.30 Log MAR, high contrast Colenbrander visual acuity of 0.20 Log MAR equivalent, low contrast Colenbrander visual acuity of 0.63 Log MAR equivalent, and a number of visible characters of 22 characters. The predicted reading speed (Y) for this participant will be:

Y= 120.74+ 0.30*(-210.44) + 0.20*(-35.83) + 0.63*(-259.83) + 22*(12.27)

Y= 156.68 words/ minute.

The best and worst predictor would depend on the individual patient's Bailey-Lovie near visual acuity, high and low contrast Colenbrander near visual acuities, and the number of visible characters. The best predictor of reading speed in the example above was the number of visible characters which increased the reading speed by 223.6%, followed by the low contrast Colenbrander near visual acuity which decreased the reading speed to 135.6% of the initial reading speed, and the Bailey-Lovie near visual acuity which

decreased the reading speed to 52.3% of the initial reading speed. The worst predictors was the high contrast Colenbrander near visual acuity decreased the reading speed by 5.9%.

7.4. Discussion

This study was intended to investigate factors affecting reading performance of people with visual impairment. Ethical approvals from the Research Ethics Committee were gained (Appendix IV). An honorary contract was required to gain approval from Cardiff and Vale University Health Board, but it took much longer than expected. Therefore, with time constraints, patients with visual impairment were replaced with people with simulated visual impairment in this study.

Simulation of visual impairment has been employed in several research studies (Wood and Troutbeck 1995, Latham et al. 2011, Butt et al. 2014). Although results of simulated visual impairment cannot be generalized to all patients with visual impairment such as patients with age related macular degeneration (Butt et al., 2014), it can be relevant to some conditions such as contrast sensitivity reduction in patients with cataract, and uncorrected presbyopia (Latham et al., 2011). Aballea and Tsuchiya (2007) suggested that simulation of visual impairment is feasible and a promising method for future research. However, they explained that simulation might be practically difficult and not all conditions can be ethically simulated. Patients with a visual impairment usually have multiple ocular conditions; therefore the advantage of simulated visual impairment is that it is possible to evaluate the effect of each factor/ visual function such as contrast reduction and reduced visual acuity, separately.

Latham et al. (2011) assessed the legibility of pharmacy labels for participants with visual impairment. They included 20 normally sighted participants aged 22.4±3.6 years, with simulated visual impairment (0.41 and 0.69 Log MAR distance visual acuity). Participants read pharmacy labels with their habitual correction and with both simulator spectacles. The authors measured reading speed and accuracy of label reading. They evaluated distance visual acuity using a Log MAR chart, and contrast sensitivity using a Mars chart. Reading acuity, critical print size, and reading speed were assessed using MNRead chart. They found that using large print pharmacy labels accurate reading speed improved by 100% in patients with mild visual impairment, and by 80% in participants with moderate visual impairment (Latham et al., 2011). In our study, we could not find the ratio of improvement because the reading speed without low vision aids was not known to us. Because participants were not able to read IREST reading chart using three visual simulators without low vision aids. Participants were able to read with both the PELVA and the optical low vision aid. Their reading speed with the PELVA and the optical low vision aid was more than 88 words/ minute (i.e. the fluent reading speed as defined by Whittaker and Lovie-Kitchin (1993)) using the three visual simulators, except that using the severe visual impairment simulator participants were able to read with the optical low vision but they did not reach the fluent reading speed of 88 words/ minute.

Butt et al. (2014) assessed the differences between contact lenses-simulated visual impairment, and visual impairment due to AMD. The authors assessed visual acuity, contrast sensitivity, and the visual fields of 5 normally sighted participants with and

without simulator contact lenses. The contact lens had a 6mm black (opaque) central pupil. They found that the simulator contact lens was useful in reducing visual acuity (17 letters on average), and reducing contrast sensitivity (7 letters on average) but not in fixation stability. The authors concluded that a contact lens with opaque centre simulated retinal blur, and caused a reduction in contrast sensitivity but it could not simulate the effect of AMD (Butt et al., 2014).

In this pilot study, we found that the PELVA significantly improved all the Bailey-Lovie near visual acuity by equivalent of 4 to 9 lines, high contrast Colenbrander near acuity by equivalent of 5 to 8 lines, and low contrast Colenbrander near acuity by equivalent of 6 to 8 lines, and reading speed with all visual impairment simulators.

The optical low vision aid significantly improved the Bailey-Lovie near visual acuity by equivalent of 2 to 7 lines, high contrast Colenbrander near visual acuity by equivalent of 3 to 6 lines, and reading speed with all visual impairment simulators. The optical low vision aid improved the low contrast Colenbrander only with moderate visual impairment simulator by equivalent of 5 lines, but did not improve it with severe visual impairment and cataract simulators. In Chapter 6, patients reported that they used PELVAs for a longer reading duration, and for near tasks that had reduced contrast such as instructions on packets. Also, the findings in Chapter 4 showed that PELVAs improved luminance contrast. These finding supporting this study finding; PELVAs might be more

useful compared to optical low vision aids for patients with low contrast or tasks that require high luminance contrast.

The difference between Bailey-Lovie near visual acuity in Log MAR and high contrast Colenbrander near visual acuity (converted into Log MAR equivalent), might be attributed by chart characteristics such as text difficulty or subjective differences, or due to the conversion of the Bailey-Lovie near visual acuity to 40 cm, and the Colenbrander near visual acuity from decimal to Log MAR equivalent.

A comparison between the PELVA and the optical low vision aids in this study was not appropriate, because different magnifications were used with the PELVA (5X) and with the optical low vision aid (3.6X). However, the PELVA was significantly better for all simulators. It is important in future to compare the reading performance of PELVAs and optical low vision aids.

However it should be noted that the PELVA significantly improved low contrast Colenbrander near visual acuity with all simulators, whereas the optical magnifier did not. This may well be due to the fact that a contrast enhancement is a feature of the PELVA (as shown in Chapter 4).

As magnification increases to the maximum the field of view will be restricted to the minimum (Schurink et al., 2011). Den-Brinker and Bruggeman (1996) reported that the

field height and width had a significant effect on reading speed. The window size was found to affect reading speed with and without navigation in patients with a visual impairment (Legge et al. 1985, Fine et al. 1996). Legge et al. (2001) suggested that if the visual span is reduced the reading rate will be lower. A field of view of 4 to 5 characters was found sufficient for fluent reading (88 words/ minute) (Legge et al. 1985, Whittaker and Lovie Kitchin 1993). However, Rayner et al. (1982) found that a window size of 15 characters to the right of the fixation point increased the reading speed. Also, Den-Brinker and Bruggeman (1996) reported that a large field of view was required for page navigation. In our study, the number of visible characters ranged from 21.67 to 22.89 characters with the PELVA, and from 9.78 to 13.50 characters with the optical low vision aid. The higher reading speed with the 5X magnification PELVA was associated with larger number of visible characters seen compared to the 3.6X magnification optical low vision aid. The 9.78 characters achieved with the optical low vision aid was associated with a reading speed of 56.38 words/ minute; this did not achieve the fluent reading of 88 words/ minute in the Whittaker and Lovie Kitchin (1993) study. Therefore, the PELVA produces a greater magnification with field of view, both of which aided the fluency of reading.

In optical low vision aids, high magnification levels restrict the field of view which significantly reduced reading speed (Dickinson and Fotinakis, 2000). This might be due to higher magnification that was not accompanied with a proportional increase in the number of saccades (Dickinson and Fotinakis, 2000). In comparison, Lowe and Drasdo

(1990) suggested that the field of view of patients with a visual impairment using CCTVs was approximately equal to the normal field of view, for manual scanning. Den-Brinker and Bruggeman (1996) found that when the window size (width and height) with CCTVs increased the time required to read a line was decreased, and the number of the required saccades was decreased. In this study, the field of view evaluated by counting the number of visible characters and this was a significant predictor of higher reading speed. Also, a larger field of view was found using the 5X PELVA compared to the 3.6X illuminated stand magnifier. This was expected as the PELVA's screen diameter is larger than that of the optical low vision aid. Also, with optical low vision aids, as magnification increases the field of view constricts and the aberration increases.

Nguyen et al. (2009) found that low vision aids (CCTVs and optical low vision aids) significantly improved reading ability, and no difference was found in reading ability between optical and electronic low vision aids. Our findings agree with all of Margrain (2000), Bowers (2000), and Nguyen et al. (2009) in that low vision aids improved reading ability.

Peterson et al. (2003) found a higher reading speed with mouse and stand EVES compared to the reading speed with optical magnifiers and the reading speed with stand EVES was higher compared to the reading speed with mouse EVES. Also, Goodrich and Kirby (2001) reported a higher reading speed and duration with the CCTV systems compared to optical low vision aids. In our study, the comparison was not appropriate

because of different magnification used with the PELVA and the optical low vision aid, although reading speed was higher using the PELVA for each simulators.

On the contrary, Nguyen et al. (2009) did not find a significant difference in reading speed between optical and electronic low vision aids. Dickinson and Shim (2007) found a lower reading speed with low vision aids (hand-held optical magnifiers). Ahn and Legge (1995) found a lower reading speed with low vision aids compared to without low vision aids, however a higher reading speed was found with spectacle mounted magnifiers, followed by hand-held magnifiers, CCTVs and then stand magnifiers.

Whittaker and Lovie-Kitchin (1993) found that reading needed a print size larger than acuity threshold, and that the effectiveness of a low vision aid depended largely on acuity reserve. They found that near visual acuity was predictive of higher reading rate. An acuity reserve of 1.5:1 achieved a 'fluent' reading speed (88 words/ minuet) and an acuity reserve of 3:1 achieved a 'high fluent' reading (174 words/ minute) (Whittaker and Lovie-Kitchin, 1993). A reading speed of 118 words/ minute was achieved with an acuity reserve of 2:1 (Latham and Tabrett, 2012). Harper et al. (1999) found that reduced visual acuity was associated with lower reading ability. Visual acuity was associated with a higher reading speed (Lovie-Kitchin et al., 2000). The authors found that the average oral reading speed, with low vision aids, of patients with near visual acuity of 1.0 Log MAR was 56 words/ minute, and 113 words/ minute for patients with near visual acuity of 0.2 Log MAR (Lovie-Kitchin et al., 2000). This agrees with our

findings; we found that near visual acuity was a significant predictor of reading speed using both PELVA and optical low vision aid using all simulators. On the other hand, visual acuity was not predictive of reading performance (Cummings et al. 1985, Legge et al. 1992, Sunness et al. 2007, Fletcher et al. 1999, Ergun et al. 2003).

In this study, we found that better low contrast acuity was a significant predictor of higher reading speed using both PELVA and illuminated stand magnifier with all visual impairment simulators including moderate and severe visual impairment, and cataract. This agrees with Whittaker and Lovie-Kitchin (1993) who found that, in patients with visual impairment, a contrast reserve of 10:1 was required for reading at 'high fluent' reading speed of 174 words/ minute; a contrast reserve of 4:1 for reading speed of 88 words/ minute, and a contrast reserve of 3:1 reserve for reading speed of 44 words/ minute i.e. spot reading. However these findings were upper-bound values, which might not be true for every patient (Whittaker and Lovie-Kitchin, 1993).

Ginsburg (1978) reported that small characters need a higher contrast level for identification rather than detection. Crossland et al. (2005) found that the baseline contrast measurements were predictive of future reading speed for patients with AMD. Legge et al. (1987) found that reading rates were highest for letters ranging in size from 0.25 to 2 degrees, within this range, reading was very tolerant to contrast reduction for 1" letters, reading rate decreased by less than a factor of two for a tenfold reduction in contrast. Brown (1981) reported that higher contrast was more critical to cataract

patients compared to AMD patients, in terms of reading performance with CCTVs. The authors also found that word recognition speed in patients with visual impairment was more predicted by contrast sensitivity (measured by Arden plates) than visual acuity. On the other hand, Van-Nes and Jacobs (1981) found that the accuracy of letters recognition did not decrease with lowering contrast to 0.12 Michelson contrast but did with further contrast reduction. Therefore, PELVAs might be useful for patients with contrast reduction such as patients with cataract because, the low contrast near acuity was significantly improved using the PELVA in this study. Also, PELVAs significantly improved the luminance contrast of a low contrast text (Chapter 4).

Legge et al. (1992) found a slower reading rate in patients who had AMD compared to other conditions. Brown (1981) found that patients who had AMD needed more magnification and more time to recognize texts compared to cataract patients. Central visual field status and ocular media status were not predictors of reading speed (Ahn and Legge, 1995). In older patients, glaucoma was associated with a lower reading speed (Ramulu et al., 2009). Mohammed and Omar (2011) found a lower reading speed in young patients (aged 13-19 years) with visual impairment (different ocular conditions) compared to a normally sighted age matched group. We did not assessed the effect of ocular conditions on reading speed. We found that using the PELVA and the optical low vision aid, reading speed was significantly lower with severe visual impairment (0.9 Log MAR) compared to moderate visual impairment and cataract simulators. No significant difference was found between cataract simulator and moderate visual impairment

simulator. However, the findings of this study might not be representative of patients with visual impairment, and therefore it is important to evaluate reading speed of patients with visual impairment (different ocular conditions).

This study was important because it evaluated factors that might affect reading performance using PELVAs. Bailey-Lovie near visual acuity, high contrast and low contrast Colenbrander near acuities, and the number of visible characters were significant predictors of reading speed. The best and worst predictors might be difficult to generalize for patients with visual impairment, because it would depend on the individual patient. However, relying on the B-Coefficient found on regression analysis; the Bailey-Lovie near visual acuity was the best predictor and the number of visible characters was the worst predictors.

The limitations of this pilot study included the small sample (n=10) (Professor Garry Rubin advised that 25 patients with visual impairment would be appropriate), and the simulation of visual impairment which might not be a true representation for patients with visual impairment, although findings do agree with previous studies. Also, only one PELVA was evaluated. It might be important to evaluate reading performance with other types of PELVAs and with a larger sample of patients with different ocular pathologies. A comparison between the PELVA and the optical low vision aid was not possible, because of the optics of the optical low vision aids as explained earlier, as we cannot compare 5X magnification using the PELVA to 3.6X equivalent magnification using the

optical low vision aid. Using a stand magnifier with a higher magnification (5X equivalent) could have made it possible to compare between the PELVA and the optical low vision aid in this study. Blurring visual acuity using plus lenses were used in this study, because it was difficult to reduce visual acuity without affecting contrast; other methods of reducing visual acuity by non-optical means should be used in future. The use of contact lenses to simulate visual impairment can be considered, however this would require an ethical approval.

The use of filters (e.g. Cambridge filters, Bangerter filters, or Vistech light scattering filters) would simulate a general blurring (image defocus, reduced visual acuity and contrast reduction) (Odell et al., 2009), but they would not simulate the effect of reducing one visual acuity alone (e.g. visual acuity reduction without contrast reduction) or a particular eye condition. However, other filters could be explored.

A fixed working distance of 40 cm (the distance at which most people read at) was used in this study. This might restrict participants to choose a closer/ more comfortable distance to read at.

7.5. Conclusion

Both PELVA and optical low vision aid significantly improved Bailey-Lovie near visual acuity, high contrast Colenbrander near visual acuity, and reading speed for participants with simulated visual impairment. Low contrast near visual acuity was improved significantly using the PELVA with all visual impairment simulators, the optical low vision aid improved the low contrast near acuity with one simulator only (moderate visual impairment simulator). The reading speed was significantly faster with the PELVA (5X magnification) than that achieved with the low magnification (3.6X) provided by the optical low vision aid. Better near visual acuity, better low contrast near acuity, and a higher number of visible characters were significant predictors/ factors of a higher reading speed using the PELVA and the optical low vision aid for all simulated visual impairment.

CHAPTER 8: Summary of thesis findings

This thesis aimed to inform those who prescribe or choose PELVAs about the functions or attributes that are most important when considering their use for people with a visual impairment.

We evaluated PELVAs from different aspects: 1) agreement between the reported PELVAs parameters' (including display screen size and magnification) and those measured in an independent setting, 2) estimation of PELVAs contrast enhancement features and resolution, 3) the prescribing patterns for PELVAs by clinicians already using them, 4) the use and satisfaction of these devices among patients with visual impairment, and 5) reading performance of participants with simulated visual impairment using PELVAs.

8.1. Main findings of the thesis

There were statistically significant differences between PELVAs measured screen diameter and reported diameter, although these differences were small (-0.03±0.07 inch) and considered unlikely to have any clinical implications.

We found that variations between reported manufacturers magnification of PELVAs and those measured in an independent setting were statistically significant. For the vast majority of PELVAs, the magnification was outside the ISO standard for magnifiers

tolerance. Clinicians should be aware that variations may occur between manufacturers reported magnification and those measured in an independent setting to ensure they meet their patients' requirements.

Some PELVAs (A, B, F, G, I, J, and K) were shown to significantly enhance the luminance contrast of a high contrast letter. All PELVAs (A-L) lie within the minimum recommended luminance contrast ratio of text and background by the ISO9241 Part3 (2008) which is 3:1, except PELVA D which was also found to give higher than expected magnification compared to manufacturers reported data (106%). This might be explained by manufacturing error, or technical faults.

Some PELVAs (A, B, F, I and K) lie within the preferred contrast ratio by Ware (2013) of 10:1. For a patient with reduced contrast sensitivity such as patients with glaucoma or cataract, PELVAs will be useful to improve a low contrast scene or target. However, whilst some PELVAs (B, C, and E) significantly improved (almost doubled) the luminance contrast of a low contrast letter, the contrast was not the same as a high contrast letter. So, for people with very much reduced contrast sensitivity it may not improve it enough.

Illumination conditions had no significant effect on the luminance contrast of PELVAs. There was no significant difference between black-on-white and white-on-black contrast viewing modes on the luminance contrast of PELVAs. The dynamic viewing

conditions (refreshed image) had an advantage over the static viewing conditions in terms of significant increase of luminance contrast.

The estimated resolution limit of some PELVAs was comparable to the resolution of a general computer screen. The resolution limit was increased with increasing magnification. High resolution is an important factor to maintain a good quality image, particularly for patients with visual impairment.

Despite PELVAs being available for prescription for patients with visual impairment on loan free of charge, only 10% of (6,668) patients attending the LVSW were prescribed these devices. Predictors for a patient (all patients) being prescribed a PELVA include: younger age, being a male, having poorer visual acuity, being registered as sight impaired or severely sight impaired, and not having AMD or cataract. These were similar to the prescribing of PELVAs in adults (> 18 years) with visual impairment. Optometrists might be less likely to offer PELVAs to older patients and women, or it may be that older patients and women were more likely to turn them down. The fact that there was no restriction on prescribing and that only 10% of patients were prescribed a PELVA provides a holistic view of the need for these devices in NHS services. These results will be useful for those planning services, and for clinicians to recognise those patients most likely to benefit from being prescribed a PELVA.

Interestingly, a larger proportion of children aged 18 years and younger were prescribed a PELVA (36.5%) compared to 10% of adults. Factors affecting this should be investigated in the future. Children age or gender did not affect the prescribing of PELVAs. Children who were prescribed a PELVA were more likely to have cataract, glaucoma or other eye conditions such as cortical visual impairment and optic nerve atrophy, and more likely to be registered as sight impaired or severely sight impaired. However, none of these was a predictor for a child being prescribed a PELVA. Other factors such as ergonomics of the devices or preference might affect the prescribing of PELVAs among children.

A larger proportion of patients used optical low vision aids compared to PELVAs and a third of the patients used both PELVAs and optical low vision aids. Some patients used other low vision aids and substitution aids. PELVAs were used more frequently than optical low vision aids for reading shop prices, reading instructions on packets, signing their own names, and doing a special hobby compared to optical devices. PELVAs were significantly more helpful than optical low vision aids for the near vision tasks performed. PELVAs were used less frequently but for a longer duration of reading compared to optical low vision aids. It would be beneficial for clinicians to demonstrate to patients (particularly younger males with poor binocular distance Log MAR visual acuity, who are registered as sigh impaired or severely sight impaired and do not have AMD or cataract) the benefits, and tasks that can be performed using a PELVA and how helpful they might be for a specific task. For example, reading instructions on packets

where contrast matters and reading for longer duration where a patient comfort matters.

For patients with simulated visual impairments, the PELVA and the optical low vision aid significantly improved Bailey-Lovie near visual acuity, high contrast Colenbrander near visual acuity and reading speed. Low contrast Colenbrander near visual acuity was improved significantly with the PELVA using all of the three visual impairment simulators. Low contrast Colenbrander near visual acuity did not improve with the optical low vision aid using severe visual impairment simulator and cataract simulator, but improved using moderate impairment simulator. Participants reading speed was higher and the number of visible characters was larger with the 5X magnification PELVA compared to the 3.6X magnification optical low vision aid. A better near visual acuity, a better low contrast near acuity, and a higher number of visible characters were significant predictors of a higher reading speed. The best and worst predictors of a higher reading speed might depend on the individual patients. PELVAs features such as contrast enhancement and a larger screen diameter of PELVAs are likely to explain the higher reading speed and the larger number of visible characters achieved with the 5X magnification PELVA compared to the lower magnification (3.6X) optical low vision aid.

8.2. Limitations of thesis

The magnification measurements were limited by manufacturers' loan period and a different sample of PELVAs was not provided to us, therefore in many cases we only

used one device. The later was a good reason not to disseminate the names of the devices.

Also, we were not able to obtain any information on the manufacturers' methodology of measuring magnification, contrast and resolution in order to be followed in our study. Only one observer measured the luminance contrast and estimated the resolution limit.

The data set provided by the LVSW had some limitations such as the lack of contrast sensitivity and near visual acuity data, and the fact that several optometrists inserted the original data set. It also required a lot of time to be cleaned.

The use of the MLVQ and the way questions were asked might limited our results in Chapter 6. In the MLVQ, the patients were asked what type of low vision aid(s) they have been using (PELVA, optical low vision aid, or other aids). In addition, there was not an option to choose an illuminated hand magnifier or stand magnifier. Hence people may have described an illuminated stand magnifier as a hand magnifier or an illuminated magnifier. Most illuminated magnifiers are hand or stand magnifiers; hence including these as options in the MLVQ is suggested. Patients with a visual impairment might have some restrictions that would deter them from accepting the phone interview such as hearing difficulty. The phone interview, although useful, might not be informative as other interview methods such as semi-structured or focused interviews (may be better).

Although these might be more valid for such studies, they are time consuming and expensive.

Ethical approvals from different committees were required for a number of studies (Chapter 6 and Chapter 7). Our original plan for Chapter 7 was to investigate factors (visual functions and/ or devices parameters) that affect reading performance of patients with a visual impairment using PELVAs and optical low vision aids. However, it took more than one year to gain an ethical approval for the study, but the honorary contract for one of the researchers was not issued. This forced us to change the original study (a cross-over study with 25 patients with a visual impairment) into 10 of patients with simulated visual impairment in the last 2 months of the PhD.

The small sample size and the simulation of visual impairment which might not be a true representation for patients with visual impairment was a limitation, although findings do agree with previous studies. Also, only one type of PELVA was evaluated. We could not compare the performance of the PELVA to the optical low vision aid as they had different magnification levels (the 5X PELVA, and the 3.6X optical low vision aid).

Blurring visual acuity using plus lenses were used in this study was a limitation, although it was difficult to reduce visual acuity without affecting contrast.

8.3. Future work

In future, it is important to repeat the magnification measurements again with an increased number of observers, and batch test PELVAs from each manufacturer, as only one of each type of PELVA was measured in the study.

It is recommended that luminance contrast should be measured with more observers and different methods such as manufacturers' methods (if they can be acquired), and resolution using a different method such as the SFRplus/ IMAtest software which will provide objective measures.

It is important to study factors that might affected the prescribing for PELVAs for children as a larger proportion of children (36.5%) compared to adults (10%) were prescribed a PELVA.

In order to obtain more specific results about the types of low vision aids used by patients with a visual impairment, the inclusion of hand-held illuminated and stand illuminated optical low vision aids as options in the MLVQ is suggested.

Evaluating the use and satisfaction of the low vision aids using a semi-structured interview instead of a phone interview is suggested because it might be more informative for such studies.

Further investigations of the factors (other than the benefit for reading or doing near vision tasks) that affect patient preference of using a particular low vision aid for a specific task such as devices ergonomics or comfort should be explored. Also, the cost effectiveness of PELVAs and optical low vision aids should be compared.

Other methods of reducing visual acuity by non-optical means should be considered in the future such as the use of contact lenses, or filters. However the use contact lenses has ethical issues, and the use of filters would simulate a general blurring (image defocus, reduced visual acuity and contrast reduction) and it would not simulate the effect of reducing visual function alone (e.g. visual acuity reduction without contrast reduction) or a particular eye condition.

It would be beneficial to evaluate reading performance with other types of PELVAs and using a larger sample of patients with different ocular pathologies or causes of visual impairment.

This thesis was important because it has been the first that evaluated the use and prescribing for PELVAs for patients with a visual impairment, and it assessed various PELVA parameters including magnification, contrast enhancement features and the resolution limit. In addition it is the first that found factors that affect the reading performance using PELVAs. It also compliments a randomized control trial being

conducted currently by Taylor et al. (2014) to determine the impact and cost effectiveness of prescribing PELVAs.

With technological development and increasing access for people in all age groups to computers and high-tech devices, electronic low vision aids might supersede conventional low vision aids. The prescribing patterns for low vision aids might change dramatically in the near future, with increased prescribing for PELVAs. Features such as affordability, ease of use, devices ergonomic, small size, portability, contrast enhancement, variable magnification, and large field of view would probably make PELVAs the low vision aids of choice for an increasing number of patients with a visual impairment. Issues such as patients' preference and comfort, and devices durability might affect the uptake of PELVAs, and these are important factors to be studied in future. Practitioners are advised to demonstrate PELVAs and their features, and give patients some time to trial them before prescribing a low vision aid. Studying the cost effectiveness of PELVAs is another important issue to be explored in order to guide services of the funding costs for patients with a visual impairment.

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APPENDICES

Appendix I: A sample of the LVSW Compact+ prescribing data set, 2011-2012

Appendix II: The Manchester Low Vision Questionnaire (MLVQ)

Appendix III: Ethics applications for Chapter 6

Appendix IV: Ethics applications for Chapter 7

Appendix V: Poster presentation (BCOVS, HOAC, OPTOM poster day)

BCOVS September 2012, Bradford, UK. (Published abstract: Okashah A, North R, Wood I, Ryan B. 2012. Pocket and portable electronic low vision aids (PELVAs): Do the manufacturers provide an accurate description?, *OPO* (33), 2012).
HOAC September 2012, Chester, UK.
OPTOM poster day May 2014, School of Optometry and Vision Sciences, Cardiff, UK.

Appendix VI: Poster presentation (AAO)

AAO October 2014, Seattle USA.

Appendix I: A sample of the LVSW Compact+ prescribing data set, 2011-2012

A sample of Compact+ prescribing data set as received from the LVSW. Type = type of visit, VA Dist = distance visual acuity in Snellen 6 metres notation, AMD = age-related macular degeneration, Diabe Eye Dis = diabetic eye diseases, Other = other ocular conditions, Not known = the diagnosis is not known/ not confirmed yet, Prescribed = prescribed a Compact+ or not, Registered = registration of visual impairment status, 0 = No, 1 = Yes, N = No, Y = Yes, VA = visual acuity

i_patient	Visit type	Gender	Age	Distance VA	Near VA	AMD	AMD Wet	AMD Dry	Diabetic Eye Disease	Cataract	Nystagmus	Other eye conditions	Other eye conditions	Not Known	Living Situation	Prescribed Compact+	Registered	Year of first Bin VA	Glaucoma	Compact+ Distance VA	Compact+ Near VA
15358	Assessment	Female	86	6/24	N10	0	0	1	0	0	0	1		0	Alone	N	Sight Impaired		0		
20982	Assessment	Male	78	6/12	N5	0	0	0	0	1	0	0		0	Alone	N			0		
5240	Assessment	Male	84	HM	N12	0	0	1	0	0	0	0		0	With other relative	N	Not Registered		0		
7648	Assessment	Female	74	6/19	N10	0	1	0	0	0	0	0		0	With Partner / Spouse	N			0		
17816	Assessment	Male	86	6/9.5	N18	0	0	1	0	1	0	0		0	Sheltered Accomodation	N	Not Known		0		
19583	Assessment	Female	77	6/60	N16	0	0	0	0	0	0	1	retinal detachment	0	With other relative	N	Sight Impaired		0		
22250	Assessment	Female	56	6/12	N6	0	0	0	0	0	0	1		0	Alone	N	Not Registered		0		
17837	Assessment	Female	85	6/24	N10	0	0	1	0	0	0	0		0	With Partner / Spouse	N	Not Registered		0		
19349	Assessment	Male	86	6/12	N8	0	0	1	0	0	0	0		0	Alone	N	Sight Impaired		0		
21059	Assessment	Female	71	6/18	N8	0	0	0	0	1	0	0		0	With Partner / Spouse	N	Not Registered		0		
5996	Assessment	Female	87	6/15	N6	0	0	0	1	1	0	0		0	With other relative	Y			0	n/a	N5
4046	Assessment	Female	84	6/18	N20	0	0	1	0	0	0	0		0	Alone	Y	Not Registered		0	n/a	N5
17498	Follow-up	Male	79													Y				n/a	N10
17498	Assessment	Male	79	6/75	N48	0	1	1	0	0	0	0		0	With Partner / Spouse	N	Not Known		0		
8661	Assessment	Male	69	6/24	N24	0	1	0	0	0	0	0		0	With Partner / Spouse	N	SSI		0		
10062	Assessment	Female	85	6/48	N24	0	1	1	0	0	0	0		0	Alone	N	Sight Impaired		0		
21028	Assessment	Female	19	6/18	N18	0	0	0	0	0	1	0		0	With other relative	N	Sight Impaired	2008	0		
21028	Assessment	Female	19	HM	N64	0	0	0	0	0	1	1		0	With other relative	N	Sight Impaired	2003	0		
20770	Assessment	Female	74	6/60	N40	0	0	1	0	1	0	0		0	Alone	N	Sight Impaired	2011	0		
15296	Assessment	Male	80	6/38	N24	0	0	0	1	0	0	0		0	With Partner / Spouse	N	Sight Impaired		0		
3963	Assessment	Male	51	6/18	N8	0	0	0	0	0	0	1	Choridu veins??	0	With Partner / Spouse	N	Not Registered		0		
3963	Follow-up	Male	51													Y				n/a	N5
17825	Assessment	Female	85	6/190	N80	0	0	1	0	0	0	0		0	Residential Care	N	Not Registered		0		
10138	Assessment	Female	71	6/120 (3/60)	N80	0	1	1	0	1	0	0		0	With Partner / Spouse	N	Sight Impaired		0		
5987	Assessment	Female	86	6/190	N24	0	0	1	0	1	0	0		0	Alone	N	Sight Impaired		0		
21745	Assessment	Male	88	6/60	N36	0	0	1	0	0	0	1		0	With other relative	N	Not Registered	2005	0		
8055	Assessment	Female	92	6/15	N8	0	0	1	0	0	0	0		0	Alone	N	Not Registered		1		
21560	Assessment	Female	82	6/7.5	N8	0	0	0	0	0	0	0		0	Alone	N			1		
12998	Assessment	Male	56	6/18	N5	0	0	0	0	1	0	1	LE blind	0	With Partner / Spouse	N	SSI		0		
20443	Assessment	Male	42	6/19	N6	0	0	0	0	0	0	0	congenital problem?	1	With Partner / Spouse	N	Not Registered		0		
22175	Assessment	Male	12	6/9.5	N14	0	0	0	0	0	0	1	leucitis + bilateral sub-	0	With other relative	N	Not Registered		0		
21314	Follow-up	Female	84													Y				n/a	N5

Appendix II: The Manchester Low Vision Questionnaire (MLVQ)

Part I: Tasks and difficulty:
Have you used/ or tried to use your low vision aid to (1-18)? If you have tried to use your magnifier(s) for this how helpful have you found them?

1. Read or tried to read ordinary print books/newsprint/ magazines/TV times
2. Read or tried to read large print books, large print newspapers, or newspaper headlines
3. Read or tried to read letters/cards/bank statements/other correspondence
4. Read or tried to read your own writing
5. Read or tried to read instructions on packets, tins, bottles, medicines, etc.
6. Read or tried to read shop prices/labels/tickets
7. Read or tried to read the markings on dials - e.g. on the cooker, radio, hi-fi, washing machine,etc.
8. Read or tried to read the telephone directory to check numbers
9. Read or tried to read the time on your watch
10. Tried to fill in forms, cheques, cards, etc.
11. Signed or tried to sign your own name
12. Written or tried to write your own letters
13. Identified or tried to identify money
14. Sewed/knitted/mended or attempted to sew, knit, or mend
15. Done or tried to do a special hobby
16. Watched or attempted to watch TV
17. Read or attempted to read street signs/bus numbers/ directions, etc.
18. Been on a trip or special day out

Part II: Frequency and duration of reading:

a. How often do you use your preferred low vision aid for reading?
b. How long can your preferred low vision aid be used at any one time for reading?

Source: Harper et al. 1999, Hinds et al. 2003

SCHOOL OF OPTOMETRY AND VISION SCIENCES

HUMAN SCIENCE ETHICAL COMMITTEE

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Project Number: 1352

Project title: Low Vision Service Wales 'Service Evaluation', effectiveness of electronic low vision aids for people with visual impairment.

Lead Investigators: Areej Okashah, Prof Rachel North, Dr Barbara Ryan

Date: 15th July 2013

With reference to the above application, I am pleased to confirm that approval has been granted,

Please inform the Research Ethics Committee immediately of any changes to the protocol, changes to personnel involved, or of any unforeseen circumstances arising from the study.

Please note the data retention periods specified by the University

- For non-funded non-clinical research, data shall be retained for no less than 5 years, or 2 years post-publication
- Undergraduate project data shall be retained at least until the end of the University appeals process

Signed:

Dr Julie Albon
Chairperson

This study will still require NRES approval before it can begin

Approval form

-----"Maureen Fallon (Cardiff and Vale UHB - Continuous Service Improvement)"
<Maureen.Fallon@wales.nhs.uk> كتب: -----
': 'Areej Okashah' <OkashahAA@cardiff.ac.uk>
: "Maureen Fallon (Cardiff and Vale UHB - Continuous Service Improvement)"
<Maureen.Fallon@wales.nhs.uk>
12:23 27/06/2013 :
: "Emma Lewis (Cardiff and Vale UHB - Research And Development)"

AOkashah SE Approval June2013

Dear Areej

Many thanks for submitting a comprehensive service evaluation proposal and the supporting information was both informative and extensive. Further to the review, I am very pleased to confirm that your project which compares optical magnifiers and portable electronic low vision aids (PELVAs) from the patient's perspectives to inform service delivery meets with service evaluation criteria. Please accept this e-mail as confirmatory approval that your project accords with Service Evaluation.

I appreciate that this is an extensive review and I look forward to receiving a copy of your findings and recommendations.

School of Optometry and Vision Sciences
Ysgol Optometreg a Gwyddorau'r Golwg
Head of School *Pennaeth Yr Ysgol* Professor *Yr Athro* Gary F. Baxter

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Invitation letter to participate in the study titled:

Low Vision Service Wales "Service Evaluation":
Effectiveness of Electronic Low Vision Aids for people with visual impairment
Rating satisfaction and use of low vision aids

Dear.....,

You are cordially invited to participate in the study titled above.

In this study, we aim to evaluate the effectiveness of electronic magnifiers compared to optical magnifiers from a user's perspective using a validated questionnaire that measures the use of low vision aids.

The study involves responding to a short phone interview (less than 15 minutes). During the phone interview you will be required to respond to 20 short questions to rate the satisfaction, the purpose, frequency, and ease of use of the magnifier(s) that you have been prescribed.

Your participation would be very valuable; it would help guide the prescription of low vision aids to best meet users' requirements and expectations. The study information sheet is attached.

If you are willing to take part in this study, please return a signed copy of the consent form in the enclosed envelope. We will call you soon in order to arrange a suitable phone interview.

Enclosed: The study information sheet, a consent form, and a stamped envelope.

Kind Regards,
Prof. Rachel North,
Dr. Barbara Ryan,
Areej Okashah

School of Optometry and Vision Sciences
Ysgol Optometreg a Gwyddorau'r Golwg
Head of School *Pennaeth Yr Ysgol* Professor *Yr Athro* Gary F. Baxter

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Cymru, Y Deyrnas Gyfunol

PARTICIPANT INFORMATION SHEET

Low Vision Service Wales "Service Evaluation": Effectiveness of Electronic Low Vision Aids for people with visual impairment

Rating satisfaction and use of low vision aids

Approval No: TBA
Version: TBA

What is this study about?

This is a service evaluation that aims to compare between optical magnifiers and portable electronic low vision aids (PELVAs) from patients' perspectives' using a validated questionnaire that measures the use of low vision aids.

Why have I been invited to take part?

You are invited to participate in this study because you have been prescribed a low vision aid for near vision, and you agreed to be contacted again for research purposes.

Do I have to take part?

Your participation is entirely voluntary and you can withdraw at any time without giving a reason; this will not affect the standard clinical care and/or service that you receive.

What will happen to me if I take part?

This study will involve a phone interview to answer a total of 20 short questions that requires short answers; in order to rate the use

and satisfaction with the current magnifier(s) that you have been prescribed. For example: During the last six weeks, have you read or attempted to read newspaper using your low vision aid? You need to answer with Yes/No. The interview should not take longer than 15 minutes of your time. Once we have received your signed consent, we will call you to arrange a suitable time for the phone interview.

Do I need to do anything special to take part?
No, you do not need to do anything special to take part in this study.

What are the possible benefits of taking part?
Your participation would be very useful as it would help guide the prescription of low vision aids, and this will help other people.

Are there any possible risks from taking part?
No risks involved in this study.

Expenses and payments:
None.

Will my results remain confidential?
Yes your information will remain confidential. All procedures are compliant with the Data Protection Act 1998. Also in accordance with the Data Protection Act this information may be retained indefinitely.

What will happen to the results of this study?
The information you provide will be held totally anonymously, so that it is impossible to trace this information back to you individually.

The information you provide will be shared with Low Vision Service Wales (LVSW) and may be used in subsequent publications (e.g. a PHD thesis and a peer reviewed journal).

Summary of the findings with appropriate format will be posted to you upon completion of the study, if you wish to receive it.

Who is funding the research?
Cardiff University.

Who has reviewed the study?
The School of Optometry Ethics Committee / Cardiff University reviewed it. Also, it has been registered as a service evaluation with NHS.

What if I have any questions or if I have a problem?
You are free to ask any question and to report any concerns at any time. Investigators contact details below:

1. **Prof. Rachel North** *The School of Optometry and Vision Sciences/ Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 2087 5114

2. **Dr. Barbara Ryan** / *The School of Optometry and Vision Sciences / Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 2087 0233

3. **Areej Okashah**/ *The School of Optometry and Vision Sciences / Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 208 74374 Ext.70247

Thank you for taking time to read this information.

School of Optometry and Vision Sciences
Ysgol Optometreg a Gwyddorau'r Golwg
Head of School *Pennaeth Yr Ysgol* Professor *Yr Athro* Gary F. Baxter

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CONSENT FORM

Low Vision Service Wales "Service Evaluation": Effectiveness of Electronic Low Vision Aids for people visual impairment

Rating satisfaction and use of low vision aids

Approval No: TBA
Version: TBA

Name of Researchers: Prof. Rachel North/ Dr. Barbara Ryan/ Areej Okashah

		Please initial box
1	I confirm that I have read and understand the Participant Information Sheet (Version: TBA Date TBA) for the above study and have had the opportunity to ask questions.	☐
2	I understand that participation is entirely voluntary and that I can withdraw at any time without giving a reason; and this will not affect the standard clinical care that I receive.	☐
3	I agree to take part in the above study.	☐
4	I wish to receive a report of study findings.	☐

Please, return a copy of the signed consent in the enclosed envelope.

Name of Participant	Date	Signature
Name of Person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

SCHOOL OF OPTOMETRY AND VISION SCIENCES

SCHOOL RESEARCH/AUDIT ETHICS COMMITTEE

Please complete the following form for consideration by assessors appointed by the Human Science Ethical Committee.

When complete, please submit all of the required documents to the Departmental Office.

1. This ethical application form
2. Participant information sheet/s
3. Consent form/s
4. Copies of advertising material

PROJECT TITLE:

Low Vision Service Wales "Service Evaluation":
Effectiveness of Electronic Low Vision Aids for people with visual impairment

Rating satisfaction and use of low vision aids

PLEASE REFER TO THE DISTINCTION BETWEEN RESEARCH AND AUDIT ATTACHED TO THIS FORM AND INDICATE INTO WHICH CATEGORY YOUR STUDY FALLS (note that the Committee does not distinguish between audit and service evaluation; both require approval)

RESEARCH AUDIT (Service Evaluation) ✓

Date of submission: **15th April 2013**

INVESTIGATOR(S): SCHOOL/ADDRESS: PHONE:

1. **Prof. Rachel North** *Cardiff University/ Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 2087 5114

2. **Dr. Barbara Ryan /Cardiff University** *Cardiff University/ Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 2087 0233

3. **Areej Okashah/ Cardiff University** *Cardiff University/ Maindy Rd. Cathays CF24 4LU* Tel. +44 (0)29 208 74374 Ext.70247

SPONSORING/COLLABORATING ORGANISATION (if any): Cardiff University

DOES THE SPONSORING/COLLABORATING ORGANISATION PROVIDE INSURANCE?

YES/NO*

IF DRUGS ARE USED DO ANY REQUIRE A CLINICAL TRIALS CERTIFICATE OR CLINICAL TRIALS EXEMPTION CERTIFICATE?

YES/NO*

*If YES please provide a copy of the certificate.

HAS THIS PROJECT BEEN APPROVED BY ANOTHER ETHICAL COMMITTEE? (e.g. NHS)? YES/NO

If yes, please provide the application, or a summary, and a copy of the decision letter. The School Committee would not normally refuse consent to a project approved by another committee, but requires notification of all work undertaken within the School or by members of the School.

DOES THIS PROJECT REQUIRE REVIEW BY THE HUMAN SCIENCESETHICAL COMMITTEE, AS PART OF AN APPLICATION TO ANOTHER ETHICAL COMMITTEE (e.g. NHS)?

YES/**NO**

Important information:
The Cardiff University Eye Clinic is considered to be NHS premises. The Human Science Ethical Committee cannot grant approval for studies where participants will be recruited by virtue of their relationship with the clinic: this includes all clinic patients and their records (even for those who have not had NHS-funded sight tests), their family and friends, and individuals recruited by advertising material located within, or immediately outside, the premises. If are considering any of the aforementioned activities in your research study, you must follow National Research Ethics Service (NRES) procedures. Further information can be found at http://www.cardiff.ac.uk/racdv/ethics/nhs/index.html.

This is a service evaluation; not research.

LAY SUMMARY OF PROJECT

1. Starting date: **30th June 2013** Duration: **4 months**

2. Description of project:

This is a service evaluation which aims to compare between optical magnifiers and portable electronic low vision aids (PELVAs) from patients' perspectives' using Manchester Low Vision Questionnaire.

3. Number of subjects to be used:

200 patients with low vision.

4.Age and gender of subjects:

Patients 60 years and older, including males and females.

5.How will subjects be recruited?

200 people with low vision from Low Vision Service Wales (LVSW). Those who have indicated they are happy to be contacted again will be contacted and asked to take part. To be determined: 100 patients who have had Compact+ (a PELVA) for a period of one year or more, and 100 patients who have had optical devices, but not Compact+ for a period of one year. Those will be identified from the service database; the first 100 in each arm. Their characteristics (e.g. age, gender, VA, etc) will be matched to enable predict factors (visual functions/ devices parameters) that could affect reading satisfaction of patients who are using portable electronic low vision aids (PELVAs).

7. Will payments be made to the subjects (if so how much)?

None.

8. Will any subjects be excluded and if so on what grounds?

No.

9. Is the activity of the subjects to be restricted in any way either before or after the procedure (e.g. diet, driving etc.)?

No.

10. Describe any hazards which could affect the health safety or welfare of any subject or of any researcher and how you propose to minimise these hazards.

None.

11. Describe any other ethical issues and how these will be addressed.

All patients who are attending the service give consent to be contacted again and they consent for the low vision clinic to access their data and contact details. However they still need to

consent to participate particularly in our project, so we are going to post them an invitation letter with study information and consent form, inviting them to take part.

12. What arrangements will there be for subjects to learn of the results of the study?

Information will be published included in a PHD thesis, and will be published in a peer reviewed journal.

A summary of the findings will be posted to participants upon the completion of the study, if requested.

13. For studies involving children or vulnerable adults, please refer to Appendix A of the Committee Guidelines and Procedures and to the University Interim Guidance for Researchers Working with Children and Young People

(Not Applicable)

http://www.cardiff.ac.uk/archi/ethics_committee/Child%20Protection%20Procedures%20-%20Interim%20Gdnce%20-%20SEOs%20031209.pdf and confirm below

Procedures are in line with School Guidelines	YES/NO
All researchers have read and understood CU Interim Guidance	YES/NO

STATEMENT BY NAMED INVESTIGATORS, HEAD OF DEPARTMENT AND RESEARCH SUPERVISOR (if necessary).

I consider that the details given constitute a true summary of the project, and the hazards and potential risks to any subject are accurately described. I confirm that the relevant health and safety measures, in accordance with University policy and School requirements, have been taken into account for the proposed research.

Lead researcher

Prof. Rachel North.....(Signed).....(Date)

Dr. Barbara Ryan .....(Signed).....(Date)

Areej Okashah .....(Signed).....(Date)

PROJECT DESCRIPTION AND PROTOCOL

PROJECT TITLE:

Low Vision Service Wales "Service Evaluation":
Effectiveness of Electronic Low Vision Aids for people with visual impairment

Rating satisfaction and use of low vision aids

Objectives of the study:

1. To evaluate what low vision aids (PELVAs and optical magnifiers) are used for i.e. the purpose of using low vision aids.

2. To evaluate and score the usefulness of low vision aids for a group of visual tasks e.g. reading a newspaper.

3. To evaluate the frequency and duration of reading that can be achieved with low vision aids.

4. To compare PELVAs and optical magnifiers from patients' perspective.

Outline of the study design

Sample:

200 people with low vision from Low Vision Service Wales (LVSW). Those who have indicated they are happy to be contacted again will be contacted and asked to take part. To be determined: 100 patients who have had Compact+ (a PELVA) for a period of one year or more, and 100 patients who have had optical devices, but not Compact+ for a period of one year. Those will be identified from the service database; the first 100 in each arm. Their characteristics (e.g. age, gender, VA, etc) will be matched to enable predict factors (visual functions/ devices parameters) that could affect reading satisfaction of patients who are using portable electronic low vision aids (PELVAs).

An ivitation letter, study information sheet, and a consent form will be posted to patients asking them if they would like to take part.

Assessment:

Patients who reply to our letter and consent to take part will be phoned to arrange a suitable time for a phone interview. During the phone interview patients are required to answer MLVQ questions to rate the satisfaction, the purpose, frequency, and ease of use of the device(s) that they were prescribed. Questionnaire items will be explained when necessary.

Patients will be asked to name the device that they have been using either optical and/ or PELVA, before answering each part of the questionnaire.

Questionnaire:

Manchester Low Vision Questionnaire (MLVQ) is a validated tool that measures the use of low vision aids. It consists of two parts (a total of 20 short questions and takes 15 minutes). The first part evaluates 1) the purpose of using of low vision aids for a group of tasks such as reading newspaper and 2) to evaluate and to rate the usefulness of low vision aids for a group of visual tasks. The second part is more specific for reading tasks as it evaluates the frequency and the duration of reading that can be achieved with low vision aids.

Outlines of the questionnaire:

What type of low vision aid(s) do you have for near vision? Is that an optical magnifier or an electronic device? Or do you have both?

Part I (The use and satisfaction of devices):

This part includes 15 short questions regarding the purpose of use and rating the satisfaction of devices.

PART I. During the last 6 weeks, have you (15 tasks) ----------? (Answer yes/no) If yes: How helpful you found PELVA/ Optical device? (Answer: Extremely/ Moderately/ Slightly/ or not at all helpful)							Comments
		YES PELVA	Rating	YES OPTICAL	Rating	NONE	
1	Read or tried to read ordinary print books/newsprint/magazines/TV times						
2	Read or tried to read large print books, large print newspapers, or newspaper headlines						
3	Read or tried to read letters/cards/bank statements/other correspondence						
4	Read or tried to read your own writing						
5	Read or tried to read instructions on packets, tins, bottles, medicines, etc						
6	Read or tried to read shop prices/labels/tickets						
7	Read or tried to read the markings on dials—eg, on the cooker, radio, hi-fi, washing						

	machine, etc						
8	Read or tried to read the telephone directory to check numbers						
9	Read or tried to read the time on your watch						
10	Tried to fill in forms, cheques, cards, etc						
11	Signed or tried to sign your own name						
12	Written or tried to write your own letters						
13	Identified or tried to identify money						
14	Sewed/knitted/mended or attempted to sew, knit, or mend						
15	Done or tried to do a special hobby						

Part II: (Frequency and duration of reading)

This part consists of four short questions to evaluate the frequency and the duration of reading (if applicable) that can be achieved with low vision aid(s).

1. How often do you use your optical LVA for reading? (Answer several times a day/ once each day/ a few times each week/ once each week/ rarely/ never)?

2. How often do you use your PELVA for reading? (Answer several times a day/ once each day/ a few times each week/ once each week/ rarely/ never)?

3. How long can your optical low vision aid be used at any one time for reading? (Answer less than 1 min/ 1-5 mins/ 6-10 mins/ 11-30 mins/ more than 30 mins/ not applicable)

4. How long can your PELVA be used at any one time for reading? (Answer less than 1 min/ 1-5 mins/ 6-10 mins/ 11-30 mins/ more than 30 mins/ not applicable)

Note: More personal responses from patients e.g. why they experienced or found this, how this can be improved, etc can be taken.

Scientific background to study

Electronic low vision aids have been available for people with low vision for some time. Table mounted electronic low vision aids (commonly known as CCTVs) have existed for many years. Subject reading speed and duration have been found to be significantly greater with the CCTV systems than with optical devices. However, their high price, lack of flexibility and portability limited their use. Head mounted devices have also been available but the benefits of these over traditional devices (e.g. optical magnifiers) have not been demonstrated, however younger patients and those with better distance vision are more likely to benefit from them. User feedback has been found to be essential to understand the benefits and shortcomings of electronic devices.

Portable electronic low vision aids (PELVAs) have advantages over other electronic devices and optical low vision aids, such as portability, lower cost, ease of use, flexible focus, variable magnification, larger field of view, and contrast adjustment.

As the cost of electronic devices is reducing and the cost of optical magnifiers is increasing, the Compact+ (a PELVA) has now become a prescribing option for people with visual impairment in the NHS, Low Vision Service Wales (LVSW). With the current pace of technological development, it is likely that electronic low vision aids will be used by many people with macular disease, especially when conventional optical low vision aids are no longer sufficient to meet their requirements.

To our knowledge there has been no literature that have evaluated users' feedback regarding the use of portable electronic low vision aids (PELVAs) reading performance with PELVAs.

We are currently investigating the parameters in commercially available PELVAs. Also, we are going to conduct a prospective study to determine the factors (devices parameters/ visual functions) that affect reading performance for patients with low vision who are using PELVAs. In addition, Barbara Ryan is collaborating with Christine Dickinson who has an NIHR grant to conduct a randomised controlled trial to determine the impact and cost effectiveness of prescribing PELVAs. This study will compliment those studies by comparing between optical and electronic low vision aids from patients' perspective.

Subjects and recruitment procedures*

200 people with low vision from Low Vision Service Wales (LVSW). Those who have indicated they are happy to be contacted again will be contacted and asked to take part. To be determined: 100 patients who have had Compact+ (a PELVA) for a period of one year or more, and 100 patients who have had optical devices, but not Compact+ for a period of one year. Those will be identified from the service database; the first 100 in each arm. Their characteristics (e.g. age, gender, VA, etc) will be matched to enable predict factors (visual functions/ devices parameters) that could affect reading satisfaction of patients who are using portable electronic low vision aids (PELVAs).

An ivitation letter, study information sheet, and a consent form will be posted to patients asking them if they would like to take part.

Substances to be administered
No substance to be administered.

Procedures:
See "assessment" page 6.

Appendix IV: Ethics applications for Chapter 7

SCHOOL RESEARCH ETHICS AUDIT COMMITTEE

Project Number: 1352

Amendment No. 2

Project title: Investigation of the factors (visual functions and/or device parameters) that affect reading performance of people with visual impairment using portable electronic low vision aids (PELVA)

Lead Investigator(s): **Prof Rachel North**

Date: 24/10/2014 Project expiry date: 24/10/2015

With reference to the above application, I am pleased to confirm that the request to amend the above ethics application has been granted.

These amendments include:

1) 10 normally sighted people (male and female)
2) Participant age: between 20 and 30 years old) normally sighted
2) Cognitively unimpaired
3) Extend until 24/10/2015

Simulators:

Simulator glasses will be used to mimic visual impairment (instead of patients with macular degeneration):

1) Refractive error (DVA Snellen equivalent of 6/12 and 6/30
2) Reduced contrast (nuclear cataract)
3) Reduced contrast (cortical cataract)
4) AMD (central scotoma)

Please inform the School Research Ethics Audit Committee immediately of any changes to the protocol, changes to personnel involved, or of any unforeseen circumstances arising from the study.

Please note the data retention periods specified by the University

- For non-funded non-clinical research, data shall be retained for no less than 5 years, or 2 years post-publication

School of Optometry and Vision Sciences
Ysgol Optometreg a Gwyddorau'r Golwg

Head of School *Pennaeth Yr Ysgol* Professor *Yr Athro* Marcela Votruba

College of Biomedical and Life Sciences
Cardiff University
Maindy Road
Cardiff
CF24 4HQ Wales
UK

Approval form 2014_0809

- Undergraduate project data shall be retained at least until the end of the University appeals process

Signed:

Dr Julie Albon, Chairperson

Approval form 2014_0809

School of Optometry and Vision Sciences
Ysgol Optometreg a Gwyddorau'r Golwg

Head of School Pennaeth Yr Ysgol Professor Yr Athro Marcela V. Baxter

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Participant Information Sheet

Study Title: Investigation of the factors (visual functions and/ or device parameters) that affect reading performance of people with visual impairment who are using pocket and portable electronic low vision aids (PELVAs)

Approval No: 2014-0809
Version 3.0 (24/10/2014)

We would like to invite you to take part in our research study. Before you decide we would like you to understand why the research is being done and what it would involve for you. One of our research team will go through the information sheet with you and answer any questions you have. We would suggest this should take about 10-15 minutes.

('Part 1' tells you the purpose of this study and what will happen to you if you take part. 'Part 2' gives you more detailed information about the conduct of the study).

Please, ask us if there is anything that is not clear.

Part 1 of the information sheet:

1.1 What is the purpose of the study?
Portable electronic low vision aids (PELVAs) have now become a prescribing option in Low Vision Service Wales (LVSW). This study will evaluate how we can predict who will find PELVAs useful and the factors that affect their usefulness.

1.2 Why have I been invited?
You are invited to take part in this study because you are 20 -30 years old and you are normally sighted.

1.3 Do I have to take part?
It is entirely up to you to decide if you wish to volunteer for the study. We will describe the study and go through this information sheet. If you agree to take part, we will ask you to sign a consent form. You are free to withdraw at any time, without giving a reason.

1.4 What will happen to me if I take part?
This study involves a visit to Low Vision Clinic at Cardiff University (the visit will take about 90-120 minutes).

You will be asked to wear simulator glasses and you will undergo a number of visual tests. These include: Visual acuity test, contrast sensitivity test, and reading performance test with and without low vision aids (electronic and optical device).

1.5 Expenses and payments:
- No payment will be provided towards your expenses for this study.

1.6 What will I have to do?
You are expected to a visit at the Low Vision Clinic, Cardiff University (the visit will take about 90-120 minutes).

1.7 What are the possible disadvantages and risks of taking part?
There are no risks involved in this study.

1.8 What are the possible benefits of taking part?
This study will help us to identify who is most likely to benefit from portable electronic low vision aids (PELVAs) and help us to develop guidance for clinicians about prescribing these devices.

1.9 What happens when the research study stops?
You do not need to do anything.

1.10 What if there is a problem?
Any concern/ complaint about the way you have been dealt with during the study or any possible harm you might suffer will be addressed. The details are included in 'Part 2' of this information sheet.

1.11 Will my taking part in the study be kept confidential?
Yes. We will follow ethical and legal practice and all information about you will be handled in confidence. The details are included in 'Part 2' of this information sheet.

If the information in 'Part 1' has interested you and you are considering participation, please read the additional information in 'Part 2' before making any decision.

Part 2 of the information sheet:

2.1 What if relevant new information becomes available?
If this occurs you will be contacted.

2.2 What will happen if I don't want to carry on with the study?
You can withdraw from the study and you can keep in contact with us to let us know your progress. Information collected may still be used.

2.3 What if there is a problem?
If you have a concern about any aspect of this study, you should contact the researchers who will do their best to answer your questions [their contact details are provided at the bottom of the information sheet].

2.4 Will my taking part in this study be kept confidential?
Yes, your results will remain confidential. All procedures are compliant with the Data Protection Act 1998. Also, in accordance with the Data Protection Act this information may be retained indefinitely. Researchers will not access your personal/ medical information at any point. Data collected during the study will be kept anonymous and will be stored in a password-protected computer.

2.5 What will happen to the results of the research study?
Study results will be kept anonymous. Results may be used in subsequent publications (e.g. a PhD thesis, and peer reviewed journals) and conference presentations.

2.6 Who is organising and funding the research?
The sponsor of this study is Cardiff University. Researchers will not be paid for including you in this study.

2.7 Who has reviewed the study?
This study has been approved by School of Optometry and Vision Sciences Ethics Committee.

2.8 Further information and contact details:
For general/ specific information about research and advice as whether you should participate, please contact:

Areej Okashah, School of Optometry and Vision Sciences, Maindy Rd, Cardiff CF24 4HQ Tel. +44 (0)29 2087 0247

For concerns/ complaints about research, please contact research team who will be happy to raise/ solve any problem that you have:

Areej Okashah, School of Optometry and Vision Sciences, Maindy Rd, Cardiff CF24 4HQ Tel. +44 (0)29 2087 0247

Prof. Rachel North School of Optometry and Vision Sciences,Maindy Rd, Cardiff CF24 4HQ Tel. +44 (0)29 2087 5114

Dr. Barbara Ryan / School of Optometry and Vision Sciences, Maindy Rd, Cardiff CF24 4HQ Tel. +44 (0)29 2087 0561

Thank you for taking time to read this information.
Please, sign attached consent form if you agree to participate in this study.

School of Optometry and Vision Sciences
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Head of School Pennaeth Yr Ysgol Professor Yr Athro Marcela V. Baxter

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Cymru, Y Deyrnas Gyfunol

Consent Form

Study Title: Investigation of the factors (visual functions and/ or device parameters) that affect reading performance of people with visual impairment who are using pocket and portable electronic low vision aids (PELVAs)

Approval No: 2014-0809
Version 3.0 (24/10/2014)

Name of Researchers: Rachel North, Barbara Ryan, Areej Okashah

Please initial box

1	I confirm that I have read and understand the Participant Information Sheet Version 3.0 (24/10/2014) for the above study. One of the research team went through the information sheet with me and I have had the opportunity to ask questions, and have had these answered satisfactorily.	☐
2	I understand that participation is entirely voluntary and that I can withdraw at any time without giving a reason.	☐
3	I understand that relevant sections of data collected during the study may be looked at by the named researchers I give permission for these individuals to have access to this data.	☐
4	I understand that data collected during the study will be kept anonymous. The results will be used in subsequent publications (e.g. a PhD thesis, and peer reviewed journals) and conference presentations and to inform the development of Low Vision Service Wales.	☐
5	I agree to take part in the above study.	☐
6	I wish to receive a report of study findings.	☐

Name of Participant	Date	Signature
Name of Person taking consent (If different from researcher)	Date	Signature
Researcher	Date	Signature

To: School of Optometry Human Science Ethical Committee

Project Number: 1352
Investigation of the factors (visual functions and/ or device parameters) that affect reading performance of people with visual impairment using portable electronic low vision aids (PELVA)

Areej Okashah, Prof Rachel North, Dr Barbra Ryan

We would like to make the following amendments to the above project:
Subjects to be recruited:

1) 10 normally sighted people (male and female)
2) Participant age: between 20 and 30 years old) normally sighted

Simulators:
Simulator glasses will be used to mimic visual impairment (instead of patients with macular degeneration):

1) Refractive error (DVA Snellen equivalent of 6/12 and 6/30
2) Reduced contrast

Low vision aids/ magnifiers:
Compact+ (a PELVA) with fixed magnification levels 5x, 7.5x, and 10x, and illuminated hand-held optical magnifiers with magnification (the required magnification level will be chosen by participant).

Clinical assessment:
Subjects who consent will undergo the following assessment (with and without simulators):

1) Distance visual acuity using LogMAR chart
2) Contrast sensitivity using a Pelli-Robson chart
3) Threshold near visual acuity using high and low contrast Bailey Lovie near LogMAR chart (with and without PELVA)
4) Reading speed using IRest test with and without low vision aids (PELVA and optical magnifiers)
5) Field of view by counting the number of characters seen with PELVA and optical magnifiers
6) Magnification and contrast settings used by patients will be recorded, if applicable.

One visit lasting approximately 45 minutes.

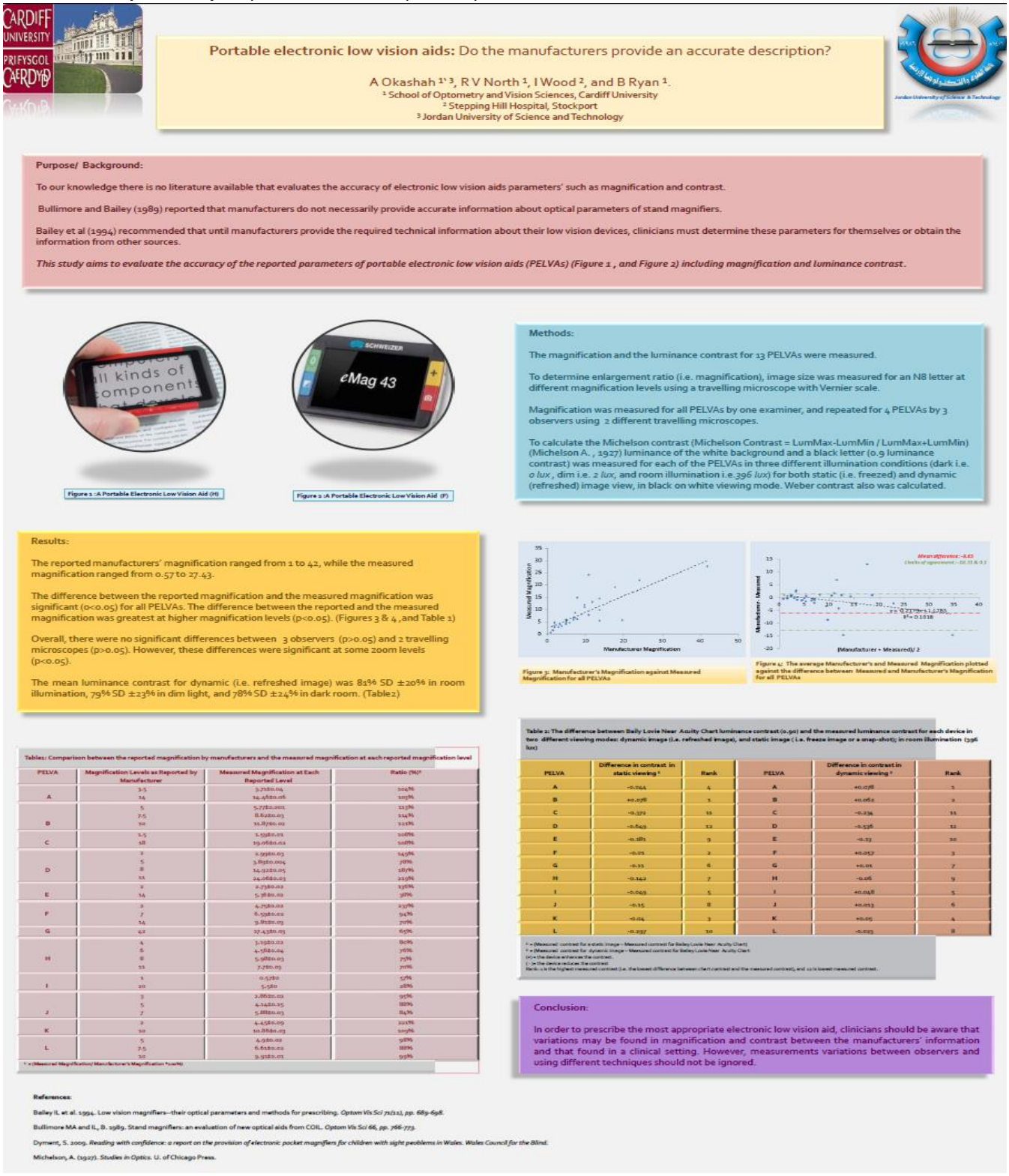
Analysis:
The reading speed and accuracy 'with' and 'without' simulators will be compared between 'with' and 'without' PELVAs (using two way ANOVA). Of the factors that affect the reading speed and accuracy including contrast sensitivity, VA at distance and near, central scotoma, field of view, or magnification will be determined using multiple regression analysis.

Appendix V: Poster presentation (BCOVS, HOAC, OPTOM poster day)

BCOVS September 2012, Bradford, UK. (Published abstract: Okashah A, North R, Wood I, Ryan B. 2012. Pocket and portable electronic low vision aids (PELVAs): Do the manufacturers provide an accurate description?, *OPO* (33), 2012).

HOAC September 2012, Chester, UK.

OPTOM poster day May 2014, School of Optometry and Vision Sciences, Cardiff, UK.



Portable electronic low vision aids: Do the manufacturers provide an accurate description?

A Okashah [1] [3], R V North [1], I Wood [2], and B Ryan [1].
[1] School of Optometry and Vision Sciences, Cardiff University
[2] Stepping Hill Hospital, Stockport
[3] Jordan University of Science and Technology

Purpose/ Background:

To our knowledge there is no literature available that evaluates the accuracy of electronic low vision aids parameters' such as magnification and contrast.

Bullimore and Bailey (1989) reported that manufacturers do not necessarily provide accurate information about optical parameters of stand magnifiers.

Bailey et al (1994) recommended that until manufacturers provide the required technical information about their low vision devices, clinicians must determine these parameters for themselves or obtain the information from other sources.

This study aims to evaluate the accuracy of the reported parameters of portable electronic low vision aids (PELVAs) (Figure 1 , and Figure 2) including magnification and luminance contrast.

Figure 1 :A Portable Electronic Low Vision Aid (H)

Figure 1 :A Portable Electronic Low Vision Aid (F)

Methods:

The magnification and the luminance contrast for 13 PELVAs were measured.

To determine enlargement ratio (i.e. magnification), image size was measured for an N8 letter at different magnification levels using a travelling microscope with Vernier scale.

Magnification was measured for all PELVAs by one examiner, and repeated for 4 PELVAs by 3 observers using 2 different travelling microscopes.

To calculate the Michelson contrast (Michelson Contrast = LumMax-LumMin / LumMax+LumMin) (Michelson A. , 1927) luminance of the white background and a black letter (0.9 luminance contrast) was measured for each of the PELVAs in three different illumination conditions (dark i.e. *0 lux* , dim i.e. *2 lux*, and room illumination i.e.*396 lux*) for both static (i.e. freezed) and dynamic (refreshed) image view, in black on white viewing mode. Weber contrast also was calculated.

Results:

The reported manufacturers' magnification ranged from 1 to 42, while the measured magnification ranged from 0.57 to 27.43.

The difference between the reported magnification and the measured magnification was significant (o<o.05) for all PELVAs. The difference between the reported and the measured magnification was greatest at higher magnification levels (p<o.05). (Figures 3 & 4 ,and Table 1)

Overall, there were no significant differences between 3 observers (p>0.05) and 2 travelling microscopes (p>0.05). However, these differences were significant at some zoom levels (p<o.05).

The mean luminance contrast for dynamic (i.e. refreshed image) was 81% SD ±20% in room illumination, 79% SD ±23% in dim light, and 78% SD ±24% in dark room. (Table2)

Figure 3: Manufacturer's Magnification against Measured Magnification for all PELVAs

Figure 4: The average Manufacturer's and Measured Magnification plotted against the difference between Measured and Manufacturer's Magnification for all PELVAs

Table1: Comparison between the reported magnification by manufacturers and the measured magnification at each reported magnification level

PELVA	Magnification Levels as Reported by Manufacturer	Measured Magnification at Each Reported Level	Ratio (%)*
A	3-5 14	3.7020.04 14.4820.06	104% 103%
B	5 7.5 10	5.7320.001 8.6220.03 11.8320.02	113% 114% 121%
C	1.5 18	1.1920.01 19.0620.02	108% 108%
D	2 5 8 11	2.1920.03 3.8920.004 14.9220.05 24.0620.03	145% 78% 187% 219%
E	2 14	2.7320.02 5.3820.02	136% 38%
F	3 7 14	4.7320.02 6.9320.02 9.8020.03	237% 94% 70%
G	42	27.4320.03	65%
H	4 6 8 12	3.1920.02 4.3620.04 5.9820.03 7.7820.03	80% 76% 75% 70%
I	1 10	0.5820 5.520	58% 58%
J	3 5 7	2.8620.02 4.1420.35 5.8820.03	95% 110% 84%
K	2 10	4.4520.03 10.2620.03	221% 103%
L	5 7.5 10	4.9320.02 6.6220.02 9.9320.01	98% 110% 99%

* = (Measured Magnification/ Manufacturer's Magnification *100)

Table 2: The difference between Daily Lovie Near Acuity Chart luminance contrast (0.90) and the measured luminance contrast for each device in two different viewing modes: dynamic image (i.e. refreshed image), and static image (i.e. freeze image or a snap-shot); in room illumination (396 lux)

PELVA	Difference in contrast in static viewing *	Rank	PELVA	Difference in contrast in dynamic viewing *	Rank
A	-0.044	4	A	+0.078	1
B	+0.098	1	B	+0.062	2
C	-0.372	11	C	-0.234	11
D	-0.643	12	D	-0.536	12
E	-0.181	9	E	-0.33	10
F	-0.01	2	F	+0.057	3
G	-0.33	6	G	+0.01	7
H	-0.142	7	H	-0.06	9
I	-0.049	5	I	+0.048	5
J	-0.35	8	J	+0.053	6
K	-0.04	3	K	+0.05	4
L	-0.237	10	L	-0.023	8

* = (Measured contrast for a static image – Measured contrast for Bailey Lovie Near Acuity Chart)
* = (Measured contrast for dynamic image – Measured contrast for Bailey Lovie Near Acuity Chart
(+)= the device enhances the contrast.
(-)= the device reduces the contrast
Rank: 1 is the highest measured contrast (i.e. the lowest difference between chart contrast and the measured contrast), and 12 is lowest measured contrast.

Conclusion:

In order to prescribe the most appropriate electronic low vision aid, clinicians should be aware that variations may be found in magnification and contrast between the manufacturers' information and that found in a clinical setting. However, measurements variations between observers and using different techniques should not be ignored.

References:

Bailey IL et al. 1994. Low vision magnifiers--their optical parameters and methods for prescribing. *Optom Vis Sci 71(11), pp. 689-698.*

Bullimore MA and IL, B. 1989. Stand magnifiers: an evaluation of new optical aids from COIL. *Optom Vis Sci 66, pp. 768-773.*

Dyment, S. 2009. *Reading with confidence: a report on the provision of electronic pocket magnifiers for children with sight problems in Wales. Wales Council for the Blind.*

Michelson, A. (1927). *Studies in Optics.* U. of Chicago Press.

Appendix VI: Poster presentation (AAO)

AAO October 2014, Seattle USA.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Portable electronic low vision aids: Do the manufacturers provide an accurate description of magnification?

I Wood [2], A Okashah [1], R V North [1] and B Ryan [1].
[1] School of Optometry and Vision Sciences, Cardiff University
[2] Stockport Stepping Hill Hospital

Stockport NHS
NHS Foundation Trust

Figure 1 A Portable Electronic Low Vision Aid

Purpose/Background:

To our knowledge there is no literature available that evaluates the accuracy of electronic low vision aids parameters' such as magnification and contrast. Bullimore and Bailey (1989) reported that manufacturers do not necessarily provide accurate information about optical parameters of stand magnifiers. Bailey et al (1994) recommended that until manufacturers provide the required technical information about their low vision devices, clinicians must determine these parameters for themselves or obtain the information from other sources.

This study aims to evaluate the accuracy of the reported parameters of portable electronic low vision aids (PELVAs) magnification (Figure 1)

Figure 2 A Travelling Microscope

Methods:

The magnification for 13 PELVAs were measured using a travelling microscope Figure 2
To determine enlargement ratio (i.e. magnification), image size was measured for an N8 letter at different magnification levels using a travelling microscope.

Table1: Comparison between the reported magnification by manufacturers and the measured magnification at each magnification levels

PELVA	Manufacturer's Magnification at Each Level	Measured Magnification at Each Level	Ratio [%]*
A	3.5	3.64	104%
	14	14.45	103%
B	5	5.68	114%
	7.5	8.58	114%
	10	12.08	121%
C	5.5	5.62	102%
	18	19.06	106%
D	2	2.98	149%
	5	3.88	78%
	8	14.92	187%
	11	24.05	219%
E*	2	2.72	136%
	16	5.35	33%
F	2	4.74	237%
	7	6.59	94%
	14	9.81	70%
G	42	27.43	65%
H*	4	3.19	80%
	6	4.55	76%
	8	5.97	75%
	11	7.7	70%
I*	1	0.57	57%
	20	5.5	28%
J*	2	2.86	85%
	5	4.88	88%
	7	5.88	84%
K	2	4.42	221%
	10	10.86	109%
L	5	4.9	98%
	7.5	6.61	88%
	10	9.91	99%

* = Small pocket PELVA; * = [Measured Magnification/Manufacturer's Magnification *100%]

Results:

The reported manufacturers' magnification ranged from 1 to 42, while the measured magnification ranged from 0.57 to 27.43.
The mean difference between the reported magnification and the measured magnification was 4.62 SD±6.42 for all PELVAs. The difference between the reported and the measured magnification was greatest at higher magnification levels. (Table1, and Figure 2)
The Bland Altman Plot in Figure 3 shows scatter of differences of the individual measurements of the magnified image remains fairly constant (±SD±0.209mm)with increased magnification. The 95% confidence interval represents +/- 0.3 of the average magnification calculated for each level measured. The greatest scatter of the individual measurements occurred with shimmer of the raster. The shimmer produced the largest 95% confidence interval of M +/- 0.325.

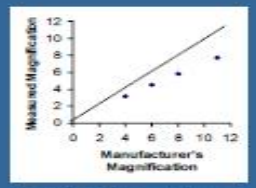


Figure 2 Magnification against measured magnification for an example PELVA

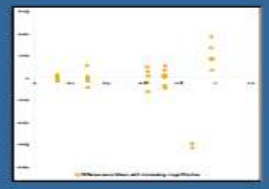


Figure 3 Difference vs Means Bland Altman Repeat Plot of an example PELVA

Conclusion:

In order to prescribe the most appropriate electronic low vision aid, clinicians should be aware that variations may be found in magnification manufacturers' information and that found in a clinical setting.

References:

Bailey IL et al. 1994. Low vision magnifiers--their optical parameters and methods for prescribing. *Optom Vis Sci* 71(11), pp. 689-698.

Bullimore MA and IL, B. 1989. Stand magnifiers: an evaluation of new optical aids from COIL. Optom Vis Sci 66, pp. 766-773.

Dyment, S. 2009. *Reading with confidence: a report on the provision of electronic pocket magnifiers for children with sight problems in Wales. Wales Council for the Blind.*